FLAT PANEL DISPLAY SUBSTRATE TESTING SYSTEM

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BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to the field of systems for processing of large substrates, and more particularly to high-throughput electron-beam flat panel display substrate (FPDS) testing systems.

Description of the Related Art

The use of electron beams to inspect and electrically test flat panel display (FPD) substrates (FPDSs) is an established technique. For FPDS testing, it is necessary to be able to test 100% of the pixels on the FPDS surface since, typically, a display with more than a few defective pixels is unusable. In some cases, if defective pixels are detected early enough in the manufacturing process, these pixels can be repaired. In other cases, if a substrate is found to have numerous defective pixels, it is more economical to scrap that FPDS prior to further processing. FPDS testing also provides process feedback: if successive FPDSs show increasing numbers of defective pixels, a deviation from proper process parameters (etch, deposition, lithography, etc.) may have occurred, which must be corrected quickly to restore normal production yields. 100% pixel inspection requires that every pixel on the FPDS must be able to be targeted by at least one of the electron beams from the linear column array.

Prior art e-beam systems for testing FPDSs employ a process chamber, pumped down to high vacuum, for containing one or more electron beam columns. The electron beams generated by these columns are scanned across the surface of the FPDS under test, thereby causing the emission of secondary electrons (SEs) and backscattered electrons (BSEs) which are collected by a detector, as is familiar to those skilled in the art. A typical FPD has a large number of pixels, arranged in an

X-Y array, each consisting of a thin-film transistor connected to a large pixel electrode. For proper operation of the FPD, it is necessary for nearly all pixels to be functional. During FPD fabrication, large numbers of pixels are connected together to "shorting bars", which, in turn, are connected to test pads around the periphery of each FPD on the FPDS. For electrical testing of the FPDS, connections are made to each of these test pads and voltages are thereby applied to the pixels in all of the FPDs on the FPDS. These electrical connections are typically made using a "probe frame", which contains a large number of contactors physically arranged to match the placement of test pads on the FPDS. After insertion of an FPDS into the process chamber, the probe frame (or its functional equivalent) is lowered onto the FPDS. Then, using the electron beams from the columns in the process chamber, electrical measurements of pixel performance may be made in order to detect if any pixels are defective.

Prior art testing systems typically employ a loadlock, attached to the process chamber, into which FPDSs for testing are loaded, pumped down, then inserted into the process chamber. After the probe frame has been lowered onto the FPDS, it may be aligned with the FPDS. If alignment is performed, no e-beam testing can be performed during the alignment process, representing a loss in system throughput. FPDSs are typically >2 m in X-Y, but <1 mm thick, and are made of glass – transporting such a delicate object clearly represents a significant difficulty, both in terms of throughput (i.e., the maximum transport speed and acceleration may be limited), and in terms of potential breakage within the system (leading to system downtime). After e-beam testing of the FPDS is completed, the probe frame is lifted off the FPDS, and the FPDS is then removed from the process chamber, followed by insertion of another FPDS into the process chamber, etc.

FIG. **1** is a schematic of a prior art multiple electron beam FPDS testing system. A typical FPDS contains a number of flat panel displays (FPDs) – six FPDs are shown in the FPDS **1398** of FIG. **1**. Each FPD contains a large number of pixels arranged in an X-Y configuration. At the stage of FPD manufacturing where e-beam testing is normally performed, each pixel typically comprises a thin-film transistor (TFT) connected to a pixel electrode (generally larger than 100 μm in both dimensions). To facilitate testing, a large number of the TFT sources are shorted together with shorting bars, connected to test pads (TPs) around the periphery of

each FPD on the FPDS. Similarly, large numbers of the TFT gates are also shorted together to other shorting bars, connected to another set of TPs. The prior art e-beam testing process is discussed in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein. In prior art e-beam FPDS testing systems as shown in FIG. **1**, after the FPDS **1398** to be tested has been inserted into the process chamber (not shown), probe frame **1399** is lowered onto FPDS **1398**. Probe frame **1399** contains a large number of contactors (not shown) which must align with, and make good electrical contact to, every one of the TPs on the FPDS. If any contactors fail to make contact with the TPs, it will not be possible to fully test the FPDS, with the result that substantial numbers of defective pixels may go undetected. Since the TPs are generally positioned around the border of each FPD, and the FPDS contains a number of FPDs, probe frame **1399** must be designed with connections both to the perimeter and the middle of the FPDS – the cross-members in probe frame **1399** crossing FPDS **1398** contain these connections.

In FIG. **1**, four electron beam columns **1311** generate electron beams **1330**, each being scanned over an area of the FPDS **1398** typically >300 mm square. The impact of the electron beams **1330** with FPDS **1398** causes the emission of secondary electrons (SEs) and backscattered electrons (BSEs). Signal electrons **1395** may comprise only SEs, only BSEs, or a mixture of SEs and BSEs. The electron optics is configured to ensure than the signal electrons **1395** from each beam **1330** are collected only by the detector **1390** associated with that particular beam **1330** in order to avoid cross-talk between pixel test signals.

Because the square scan areas of the beams **1330** do not fully span the width of FPDS **1398**, it is necessary to mount FPDS **1398** on an X-Y stage in order to position any point on the FPDS **1398** surface under one of the beams **1330**. The stage comprises motion axis position sensors **1386** and **1387** and stage motors **1360** and **1361**, as is familiar to those skilled in the art. Because the dimensions of the FPDS are >2 m in each axis, the X-Y stage must be very large, leading to high cost and potential reliability and maintenance issues. It would be advantageous to eliminate the need for an X-Y stage in an FPDS testing system.

Cables **1312** connect columns **1311** to optics control **1301**. Cables **1391** connect detectors **1390** to detectors control **1304**. Data lines **1310** connect position

sensors **1386** and **1387** to X-Y position readout **1302**. Cables **1325** connect stage motors **1360** and **1361** to stage control **1300**. Controls **1300-1302**, and **1304**, are connected to system control **1303** by control links **1326**, **1320**, **1319**, and **1392**, respectively. Cable **1385** conducts control signals to the probe frame **1399** from system control **1303**.

There are a number of disadvantages for prior art FPDS electron-beam testing methods:

1) The FPDS, with typical dimensions >2 m in X and Y, must be supported during testing by a large and expensive X-Y stage, which enables the FPDS to be moved around under one or more electron beams for testing of the entire FPDS surface (100% of all pixels).

2) Connection to the test pads on the FPDS requires a probe frame, which remains in the process chamber and must be aligned to the test pads for proper electrical connections. The use of a probe frame has several significant disadvantages:

   a. The probe frame-to-FPDS alignment step is performed within the process chamber – it is not possible to test the FPDS during this step, thus system throughput is adversely affected. In addition, it may be more difficult to achieve good alignment due to the difficulty of working within the confines of the process chamber.

   b. If the probe frame-to-FPDS alignment is accelerated or omitted to improve throughput, there will be cases in which some test pads are not connected to the testing system electronics, causing large numbers of pixels to go untested.

   c. When there is a change in the FPDS design, the process chamber must be opened to replace the probe frame since the probe frame design must be consistent with the particular arrangement of test pads on the FPDS. This has a serious negative impact on throughput and tool availability.

   d. If there is a failure of the probe frame, the process chamber must be opened for replacement or repair of the probe frame – during this time, the system is down.

e. Because prior art systems use an X-Y stage to move the FPDS during testing, moving cables are required to make contact to the probe frame which is moving along with the FPDS. It is well known by those skilled in the art that two major sources of system unreliability are cables and cable connectors, especially if the cables connect to a moving assembly such as the probe frame.

3) Prior art electron-beam FPDS testing systems generally transport the FPDS without any protective surroundings, e.g. a pallet, for physical support – this raises issues of potential FPDS breakage within the FPDS testing system, leading to system downtime while fragments of the broken FPDS are removed from valves, mechanisms, pump openings, etc.

4) In prior art testing systems, when the FPD fab switches from one size FPDS to another (usually larger) size FPDS, typically either substantial changes to the testing system are required, or an entirely new testing system is needed.

Thus there is a need for an electron-beam FPDS testing system with the following improvements from prior art e-beam FPDS testing systems:

1) Elimination of the need for a large and expensive X-Y stage for supporting the FPDS under test.

2) Elimination of a probe frame which remains in the process chamber, and substituting a method of connecting to the test pads on the FPDS which eliminates the disadvantages of prior art system designs described above.

3) Elimination of all moving cables and cable connectors between the FPDS under test and the system.

4) Adding a capability for rapid changeover from one size FPDS to another size FPDS with minimal or no system downtime.

SUMMARY OF THE INVENTION

The present invention includes an equally spaced linear array of electron beam columns, each configured with a main scan axis parallel to the linear array of

electron beam columns such that the scans of neighboring columns overlap, thereby providing 100% scanning across the full width of the FPDS under test. The multiple electron beam columns may instead be multiple ion beam columns, each generating a single ion beam which is focused onto the surface of the FPDS for imaging and/or testing purposes. The present invention provides a system for testing of FPDSs which addresses all three areas for improvement described in the background of the invention:

1) Instead of the X-Y stage, the present invention employs a set of bi-directional motor-driven rollers to move a pallet containing the FPDS along one axis within the process chamber, while a line of e-beam columns (oriented perpendicularly to the FPDS motion axis) tests pixels across the full width of the FPDS. The pallet provides physical support and protection for the delicate FPDS at all times within the system.

2) Instead of using a probe frame, the present invention uses the pallet described above to also provide electrical connection to the test pads on the FPDS. Advantages of electrically connecting to the FPDS using a pallet include:

   a. Since the pallet travels with the FPDS throughout the system, it does not remain within the process chamber. Alignment of contactors to test pads may be done simultaneously with e-beam testing of another FPDS (thereby improving throughput).

   b. Since alignment of the contactors to the test pads is done outside the confines of the process chamber, potentially alignment may be easier and/or faster. Also, since alignment now has no effect on throughput, it is possible take sufficient time for alignment to ensure that all contactors are making proper contact prior to insertion of the pallet into the process chamber – thus e-beam testing need never be aborted due to contact failure within the process chamber.

   c. When there is a change in the FPDS design, different pallets (adapted to the new FPDS design) can be immediately

substituted with no need to open the process chamber and with no loss in throughput or system availability.

d. If there is a failure of the contactors on a particular pallet, another pallet may be substituted, with no need for opening the process chamber and with minimal throughput effect.

3) Rather than using moving cables and cable connectors between the FPDS under test and the system, a method of wireless communication is used to/from the pallet as it moves within the process chamber, thereby improving system reliability.

4) Since the pallet transport mechanisms deal only with pallets and not with the FPDS, it is simple to convert the testing system from one size FPDS to another size by using a different pallet (having the same X-Y outer dimensions), with no system downtime for the conversion.

The detailed specification is divided into a number of sections, each describing various aspects of the present invention. Some of these sections apply to both embodiments, while others apply to only the first embodiment or only to the second embodiment. Each section is described briefly below:

Flat Panel Display Substrate Pallet Design

FIGS. **3-9** describe the overall mechanical design of the FPDS pallet used in both embodiments. The pallet has a pallet top and a pallet bottom, with provision for the FPDS to be clamped between them.

Internal Structure and Electronics of the Pallet

FIGS. **10-17** describe the electronics within the pallet used in both embodiments, including the internal drive electronics which provides voltages to contactors which connect to test pads on the FPDS under test, as well as wireless data links to/from the system control, and three alternative means for supplying power to charge batteries in the pallet.

Pin Plate and Robot End Effector Design

FIGS. **18-25** describe the design of the pin plate used to disassemble pallets, and the robot end effector used to remove FPDSs from disassembled pallets. The pin plate and end effector designs apply to both the first and second embodiments.

Detailed Pallet Disassembly Procedure

FIGS. **26-33** show the disassembly procedure for pallets in detail. Two sets of pins (long and short) on the pin plate are able to separate the pallet top, FPDS, and pallet bottom in one vertical actuator-driven motion. After the pallet is separated, the robot end effector is able to enter the assembly (which is being held apart by the pin plate), remove the already-tested FPDS, insert another FPDS (ready for testing), and then reassemble the pallet. This procedure applies to both the first and second embodiments.

Procedure for Aligning the Pallet Top to the FPDS

FIGS. **34-40** illustrate a procedure for aligning the pallet top with the FPDS. This alignment is necessary to ensure that all of the large number of contactors in the pallet top align (to within a few μm) with the test pads on the FPDS under test. Two alternative means for detecting alignment marks on the FPDS are described, along with a procedure for precisely moving the pallet top in X-Y-Yaw relative to the FPDS. After proper alignment has been achieved, the pallet top and pallet bottom are firmly locked together, clamping the FPDS under test between them. This alignment and clamping procedure applies to both the first and second embodiments.

First Embodiment of an FPDS Testing System

FIGS. **41-44** describe a first embodiment of the present invention, comprising three subsystems: a pallet elevator, a dual loadlock, and a process chamber. The pallet elevator is the interface to the FPD fab, while the dual loadlock enables the process chamber to run nonstop testing of FPDSs using a multiple electron beam column assembly with no down-time for pumping down or venting the loadlock.

Pallet X-Y-Yaw Positional Measurement System

FIGS. **45-50** discuss a system for measuring the X-Y-Yaw position of the pallet during e-beam testing. Given the X-Y-Yaw positional data, the system control directs the optics control to deflect the multiple e-beams to correct for any positional errors. The X-Y-Yaw positional measurement system applies to both the first and second embodiments.

Pallet Transfer between Pallet Elevator, Dual Loadlock, and Process Chamber

FIGS. **51-58** illustrate the pallet transfer process back and forth between the pallet elevator and dual loadlock, and back and forth between the dual loadlock and the process chamber in the first embodiment.

Pallet Disassembly and FPDS Removal from Pallet Elevator

FIGS. **59-63** describe the following: disassembly of two pallets within the pallet elevator, then removal of FPDSs from the pallet elevator into the FPD fab. The process for insertion of FPDSs for testing, then pallet reassembly, is the reverse: FIGS. **63-59**. The process shown applies only to the first embodiment.

Timing Diagram for the First Embodiment of an FPDS Testing System

FIG. **64** is a timing diagram for the first embodiment of the present invention describing the 240 s cycle during which four FPDSs are fully tested by the multiple e-beam column assembly within the process chamber.

Second Embodiment of an FPDS Testing System

FIGS. **65-70** describe a second embodiment of the present invention, comprising two subsystems: a dual loadlock and a process chamber. The functions provided by both the pallet elevator and the dual loadlock in the first embodiment are combined into the dual loadlock in the second embodiment. This saves FPD fab floor space which is typically at a premium. The process chamber for the second embodiment is identical to that of the first embodiment.

Timing Diagram for the Second Embodiment of an FPDS Testing System

FIG. **70** is a timing diagram for the second embodiment of the present invention describing the 240 s cycle during which four FPDSs are fully tested by the multiple e-beam column assembly within the process chamber.

Schematic View of the Electron Optical Column and Detector Optics

FIG. **71** is a schematic cross-section of one of the electron optical columns **1211** and the corresponding detector **1240** shown in FIG. **2**. Details of the electron source, focusing lenses, beam blanker, and deflectors are shown.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a schematic of certain functional elements of a prior art multiple electron beam FPDS testing system;

FIG. **2** is a schematic **99** of certain functional elements of a multiple electron beam FPDS testing system according to the present invention;

FIG. **3** is a schematic isometric view of a pallet **100**;

FIG. **4** is a schematic top view of pallet **100** in FIG. **3**;

FIG. **5** is a schematic side view of pallet **100** in FIG. **3**;

FIG. **6** is a schematic end view of pallet **100** in FIG. **3**;

FIG. **7** is a schematic bottom view of pallet **100** in FIG. **3**;

FIG. **8** is a schematic view through section A-A of pallet **100** in FIG. **4**;

FIG. **9** is a schematic view through section E-E of pallet **100** in FIG. **7**;

FIG. **10** is a schematic diagram of the circuits within pallet **100**, external communication circuits to/from pallet **100**, and an inductive power transfer system;

FIG. **11** is a schematic diagram of the circuits within pallet **100**, external communication circuits to/from pallet **100**, and a radiative power transfer system;

FIG. **12** is a schematic diagram of the circuits within pallet **100**, external communication circuits to/from pallet **100**, and a dual roller power transfer system;

FIG. **13** is a schematic view through section B-B showing the internal power system of pallet **100** in FIG. **6**;

FIG. **14** is a schematic view through section F-F showing the internal power system of pallet **100** in FIG. **4**;

FIG. **15** is a schematic view through section C-C showing the internal data bus of pallet **100** in FIG. **6**;

FIG. **16** is a schematic view through section D-D showing the connections between the internal drive electronics and the FPD test pads on the FPDS within pallet **100** in FIG. **6**;

FIG. **17** is schematic detail view **121** of contactors **425** connecting to FPD test pads **426** on FPDS **120** within pallet **100** in FIG. **3**;

FIG. **18** is a schematic isometric view of pallet **100** and pin plate **202**, illustrating the insertion direction for pin plate **202** into pallet **100**;

FIG. **19** is a schematic top view with a partial cutaway of pallet **100** and pin plate **202** in FIG. **18**;

FIG. **20** is a schematic side view of pallet **100** and pin plate **202** in FIG. **18**;

FIG. **21** is a schematic end view of pallet **100** and pin plate **202** in FIG. **18**;

FIG. **22** is a schematic isometric view of a robot end effector;

FIG. **23** is a schematic top view of the robot end effector in FIG. **22**;

FIG. **24** is a schematic side view of the robot end effector in FIG. **22**;

FIG. **25** is a schematic end view of the robot end effector in FIG. **22**;

FIG. **26** is a schematic isometric cutaway view of pallet **100** and pin plate **202** in FIG. **18** showing pin plate **202** disassembling pallet **100**;

FIG. **27** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing pin plate **202** before insertion into pallet **100**;

FIG. **28** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing pin plate **202** inserted into pallet **100**, positioned to separate pallet top **110** from pallet bottom **112**;

FIG. **29** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing pin plate **202** inserted into pallet **100**, positioned to separate FPDS **120** from pallet bottom **112**;

FIG. **30** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing pin plate **202** fully inserted into the separated pallet;

FIG. **31** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing a robot end effector entering the separated pallet underneath FPDS **120**;

FIG. **32** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing the robot end effector lifting FPDS **120** off pin plate **202**;

FIG. **33** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19** showing the robot end effector removing FPDS **120** from the separated pallet;

FIG. **34** is schematic detail view **122** showing capacitive sensor **1002** detecting the location of passivated alignment mark **1001** on FPDS **120** in FIG. **3**;

FIG. **35** is a schematic view of capacitive sensor **1002** and its associated electronics;

FIG. **36** shows alignment mark **1034** underneath capacitive sensor **1002** in the case of FPDS misalignment;

FIG. **37** shows alignment mark **1034** underneath capacitive sensor **1002** in the case of correct FPDS alignment;

FIG. **38** is schematic detail view **123** of an optical sensor detecting the location of passivated alignment mark **1001** on FPDS **120** in FIG. **3**;

FIG. **39A** is a schematic view of X-Y-Yaw relative motion vectors between the pallet top **110** and pallet bottom **112** for alignment of contactors **425** with pads **426** as shown in FIG. **17**;

FIG. **39B** is detail view **1155** with partial cutaway of X-Y-Yaw actuators mounted between pallet top **110** and pallet bottom **112** in FIG. **39A**;

FIG. **40** is a schematic detail view **124** of a locking mechanism between pallet top **110** and pallet bottom **112** in pallet **100** in FIG. **3**;

FIG. **41** is a top view of a first embodiment of an FPDS testing system embodying the present invention, including pallet elevator **629**, dual loadlock **575** and process chamber **522**;

FIG. **42** is a side view of the FPDS testing system in FIG. **41**;

FIG. **43** is a schematic view through section H-H of the FPDS testing system (pallet elevator not shown) in FIG. **41**;

FIG. **44** is a schematic view through section G-G of the FPDS testing system in FIG. **42**;

FIG. **45** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing a method for

measurement of the X-Y-Yaw position of pallet **572** within process chamber **522** – pallet **572** is shown mostly within dual loadlock **575**;

FIG. **46** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **572** half way into process chamber **522**;

FIG. **47** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **572** mostly within process chamber **522**;

FIG. **48** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **600** with an offset from its desired position **601** along the X-axis **573**;

FIG. **49** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **603** with an offset from its desired position **604** along the Y-axis **574**;

FIG. **50** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **606** with Yaw (rotation about a vertical axis) **608** from its desired orientation **607**;

FIG. **51** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while processed pallet (i.e., a pallet containing an already-tested FPDS) **602** is being removed from lower loadlock **505** into pallet elevator **629**;

FIG. **52** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while pallet elevator **629** is indexing to enable insertion of unprocessed pallet (i.e., a pallet containing an FPDS ready for testing) **604** from pallet elevator **629** into lower loadlock **505**;

FIG. **53** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while unprocessed pallet **604** is being inserted from pallet elevator **629** into lower loadlock **505**;

FIG. **54** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while pallet elevator **629** is indexing to enable removal of processed pallet **603**;

FIG. **55** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while processed pallet **603** is being removed from lower loadlock **505** into pallet elevator **629**;

FIG. **56** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while pallet elevator **629** is indexing to enable insertion of unprocessed pallet **605** from pallet elevator **629** into lower loadlock **505**;

FIG. **57** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while unprocessed pallet **605** is being inserted from pallet elevator **629** into lower loadlock **505**;

FIG. **58** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **604** from lower loadlock **505** being tested while processed pallet **600** is being removed from upper loadlock **502** into pallet elevator **629**

FIG. **59** is a schematic side view of the FPDS testing system in FIG. **42** with a cutaway showing two assembled pallets **701** and **702** in pallet elevator **629**;

FIG. **60** is a schematic side view of the FPDS testing system in FIG. **42** with a cutaway showing two disassembled pallets in pallet elevator **629**;

FIG. **61** is a schematic side view of the FPDS testing system in FIG. **42** with a cutaway showing a three-blade robot entering pallet elevator **629**;

FIG. **62** is a schematic side view of the FPDS testing system in FIG. **42** with a cutaway showing the three-blade robot lifting two tested FPDSs **721** and **724** off two pin plates **705** and **706**, respectively;

FIG. **63** is a schematic side view of the FPDS testing system in FIG. **42** with a cutaway showing the three-blade robot removing two tested FPDSs **721** and **724** from pallet elevator **629**;

FIG. **64** is an operational cycle timing diagram for the FPDS testing system in FIGS. **41** and **42**;

FIG. **65** is a schematic top view of a second embodiment of an FPDS testing system;

FIG. **66** is a schematic side view of the FPDS testing system in FIG. **65**;

FIG. **67** is a schematic view through section K-K of the FPDS testing system in FIG. **65** showing an FPDS in pallet **807** from upper loadlock **800** being tested while a two-blade robot is entering lower loadlock **800**;

FIG. **68** is a schematic view through section L-L of the FPDS testing system in FIG. **66**;

FIG. **69** is a schematic view through section K-K of the FPDS testing system in FIG. **65** showing an FPDS in pallet **907** from lower loadlock **801** being tested while the two-blade robot is entering upper loadlock **800**; and

FIG. **70** is an operational cycle timing diagram for the FPDS testing system in FIGS. **65** and **66**.

FIG. **71** is a schematic cross-section of one of the electron optical columns **1211** and the corresponding detector **1240** shown in FIG. **2**.

DETAILED DESCRIPTION

FIG. **2** is a schematic **99** of certain functional elements of a multiple electron beam system for testing substrates. Although the present invention applies to various types of substrates requiring electrical testing, the following disclosure describes in detailed example a FPDS testing system according to the present invention. To avoid the disadvantages of a probe frame which were discussed in reference to FIG. **1**, FPDS **120** (which may have a plurality of FPDs, such as six FPDs in the FPDS shown in FIG. **2**) is carried in a pallet **100** which provides the following benefits during the operation of an FPDS testing system **99** according to the present invention:

1) Pallet **100** supports and protects the delicate FPDS **120** during transport and e-beam testing within the process chamber (not shown) – this support virtually eliminates the chance of FPDS breakage in the system which would lead to unplanned tool downtime. In the prior art, the FPDS alone is transported through the testing system with no protection against breakage.

2) The pallet **100** supplies electrical connections to the FPDS under test – if a contactor within the pallet fails, the pallet can be replaced with no need to vent and open a process chamber of the present invention,

which will be described in reference to the figures of the drawing. There is also no impact on either throughput or tool availability.

3) The pallet **100** contains internal alignment mechanisms which enable the pallet contactors to be accurately aligned to all of the test pads on the FPDS **120** with no impact on throughput – see FIGS. **39A-39B** (this is accomplished by performing the alignment step outside the process chamber, while another FPDS is being tested).

4) The pallet **100**, in conjunction with a linear array of e-beams spanning the full width of the FPDS, eliminates the need for an X-Y stage, thereby substantially reducing system cost and increasing reliability.

5) If there is a change in the FPDS design, a new pallet (with different connections to the test pads, if necessary) can be substituted with no effect on either throughput or tool availability.

6) Since the pallet **100** interacts with the FPDS testing system using wireless communication, all moving cables are eliminated, improving reliability.

7) The FPDS testing system can use pallets containing FPDSs of different sizes as long as the outer dimensions of the pallets are the same – there is no system downtime for the conversion. This capability enables the system design to have increased extensibility to future FPDS generations.

Pallet **100** is supported by bi-directional motor-driven rollers **627** to transport pallet **100** into and out of the process chamber (not shown) along direction **1299**.

Each column **1211** includes an electron source for generating an electron beam **1230**, one or more lenses for focusing electron beam **1230** onto the surface of FPDS **120**, and a deflector for deflecting electron beam **1230** on the surface of FPDS **120**. The design of columns **1211** is optimized to scan beams **1230** substantially along an axis perpendicular to the direction of travel **1299** (X direction) of pallet **100**. FIG. **71** is a schematic cross-section of one of the electron optical columns **1211** and the corresponding detector **1240** shown in FIG. **2**. Details of the e-beam testing process applicable to the present invention are discussed in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein.

In FIG. **2**, five electron beam columns **1211** generate electron beams **1230**, each beam **1230** being configured to scan substantially along an axis perpendicular to the direction of travel **1299** of pallet **100**. The scan distance of each beam **1230** is typically ~125 mm wide and the spacing of columns **1211** is less than or equal to the width of the beam scans, thus neighboring scans overlap or abut, enabling the full width of FPDS **120** to be scanned with at least one e-beam **1230** without the need for motion in the Y direction. This allows the entire X-Y surface of FPDS **120** to be scanned using motion along only one axis **1299** (X axis), with pallet **100** supported and moved by the set of bi-directional motor-driven rollers **627**.

As for the prior art in FIG. **1**, the impact of the electron beams **1230** with FPDS **120** causes the emission of secondary electrons (SEs) and backscattered electrons (BSEs). Signal electrons **1244** may comprise only SEs, only BSEs, or a mixture of SEs and BSEs. The detector optics design is configured to ensure than the signal electrons **1244** from each beam **1230** are collected only by the detector **1240** associated with that particular beam **1230** in order to avoid cross-talk between pixel test signals. Details of the detector optics design and operation applicable to the present invention are discussed in U.S. Patent Application Ser. No. 11/093,000 filed March 28, 2005 and in U.S. Patent Application Ser. No. 11/355,256 filed February 14, 2006, both incorporated by reference herein.

The FPDS testing system of the present invention in FIG. **2** utilizes a different method for measuring and controlling the position of FPDS **120** under testing e-beams **1230** than is used in the prior art of FIG. **1**. Position sensors **550-553** emit laser beams **568-571**, respectively, toward the reflective sides of pallet **100**. The laser beams are then reflected off the sides of pallet **100** back to each sensor **550-553**, respectively (i.e., with no crosstalk between sensors **550-553**). Sensors **550-553** may employ various methods of determining the distances from each sensor to the reflective sides of pallet **100**, including laser interferometry, laser beam triangulation, or some other method for distance determination – the accuracy of the X-Y-Yaw position measurements preferably should be in the ~2-10 μm range, substantially smaller than the dimensions of the test pads on the FPDS **120**. The respective distances from each of sensors **550-553** to pallet **100** can then be used to accurately determine the pallet X-Y-Yaw position as is familiar to those skilled in the

art. Details of the pallet X-Y-Yaw position sensing methodology are given in FIGS. **45-50**, below.

System control **1203** sends control signals along data line **498** to data transmitter **554** which transmits signal beam **556** to data receiver **442** mounted in the side of pallet **100**. Pallet **100** communicates with system control **1203** using data transmitter **440** (mounted in the side of pallet **100**) to transmit signal beam **557** to data receiver **555**. The signal from data receiver **555** passes along data line **499** to system control **1203**.

The signals being transmitted from system control **1203** to pallet **100** include the following:

1) Data on the X-Y-Yaw position of pallet **100** relative to optics assembly **520** (first embodiment) or **806** (second embodiment). The pallet uses this data to determine which pixels are within range of beams **1230**, and therefore which test pads should have voltages sent to them for activating the thin-film transistors which drive the pixel elements to be tested.

2) Confirmation of status information received – this allows pallet **100** to verify that system control **1203** received the correct status information.

3) Control information for when to activate battery charger **406** (FIG. **10**), **471** (FIG. **11**), or **482** (FIG. **12**).

4) Any other necessary control information needed by internal drive electronics **410**.

The signals being transmitted from pallet **100** to system control **1203** include the following:

1) Confirmation of X-Y-Yaw data received – this allows system control **1203** to verify that pallet **100** received the correct X-Y-Yaw data.

2) Status information on internal drive electronics **410** and the charge state of battery **408**.

Signal beams **556** and **557** may be any form of radiation capable of being modulated with the control data, such as radio waves, IR, visible light, or UV. An important advantage of the present invention over the prior art is the complete elimination of cables and cable connectors between system control **1203** and the FPDS **120** under test which is moving along direction **1299** within the process

chamber (not shown). The elimination of cables and cable connectors leads to higher throughput (since the speed of pallet **100** is not limited by the cables) and increased reliability.

Cables **1212** connect columns **1211** to optics control **1201**. Cables **1241** connect detectors **1240** to detectors control **1242**. Data lines **1210** connect position sensors **550-553** to X-Y-Yaw readout **1202**. Cables **1225** connect bi-directional motor-driven rollers **627** to rollers control **1200**. Controls **1200-1202** and **1242** are connected to system control **1203** by control links **1226**, **1220**, **1219**, and **1243**, respectively.

FLAT PANEL DISPLAY SUBSTRATE PALLET DESIGN

FIG. **3** is a schematic isometric view of a pallet **100**. Pallet **100** includes pallet top **110** and pallet bottom **112**, with provision for an FPDS **120** to be clamped between them. Typically, multiple flat panel displays (FPDs) will be fabricated on a single FPDS **120** – pallet top **110** is configured with cross-members **114** and **116** which cover areas on FPDS **120** which are not to be tested or otherwise processed, but which typically contain test pads connecting to shorting bars as discussed in FIG. **1**. Detail view **121** shows contactors making electrical connections with test pads on FPDS **120** (see FIG. **17**). Detail view **122** shows a capacitive sensor locating an alignment mark on FPDS **120** (see FIGS. **34-37**). Detail view **123** shows an optical sensor locating an alignment mark on FPDS **120** (see FIG. **38**). Detail view **124** shows a locking mechanism between pallet top **110** and pallet bottom **112**.

FIGS. **4-7** are schematic top, side, end and bottom views, respectively, of pallet **100** in FIG. **3**. In the top view in FIG. **4**, the overall X-Y pallet dimensions **130** and **132** are shown. Also shown is outline **146** of FPDS **120**. The X-Y dimensions of pallet **100** must be somewhat larger than the X-Y dimensions of FPDS **120** in order to accommodate internal drive electronics **410** within pallet **100** (see FIGS. **13-16**). Clearly, pallets with the same overall dimensions **130** and **132** can accommodate any generation FPDS which has the same size as outline **146**, or is smaller than outline **146** – this is a key advantage of the present invention relative to the prior art: a single FPDS testing system can test multiple FPDS generations with no need for any system hardware modifications. As long as the system is designed to handle sufficiently large pallets, a number of FPDS generations can be accommodated with

a single FPDS testing system. For example, a "Gen-9" tool is fully capable of testing "Gen-8" or "Gen-7" FPDSs with no tool downtime for conversion. Any changes to the e-beam testing procedure required when converting between FPDS generations can be done entirely within system control **1203** which drives the test signals to/from pallet **100** – these changes would typically involve software modifications only. Often, even within a given FPDS generation, the layout of test pads and/or alignment marks on the FPDS can change – with the present invention, only modifications to the pallet top would be required (to reconfigure the positions of contactors and/or alignment mark detectors) which can be done off-line from system operation, and thus would have no effect on either system throughput or system availability (i.e., there is no downtime for changing the probe frame).

Dimensions **134** and **136** show the distances along the X-axis (horizontal in FIG. **4**) from outline **146** to the sides of pallet **100**. Dimensions **138** and **140** are the distances along the Y-axis (vertical in FIG. **4**) from outline **146** to the sides of pallet **100**. The openings for each FPD on FPDS **120** have dimensions **142** (along the X-axis) and **144** (along the Y-axis). Here, all the FPDs on the FPDS **120** are assumed to have the same size, however this is not mandatory for the pallet concept. Cross-members **114** and **116** extend across areas of FPDS **120** between the individual FPDs, and may contain contactors for electrical connection to test pads on FPDS **120** (see FIG. **17**). Cross-sections A-A and F-F through pallet **100** are also illustrated in FIG. **4**.

In the side view of pallet **100** shown in FIG. **5**, pallet height **139** is exaggerated relative to the (horizontal) X-axis dimension. The heights of pallet top **110** and pallet bottom **112** stack up to generate pallet height **139**.

FIG. **6** is an end view of pallet **100**, again showing the stacking of pallet top **110** and pallet bottom **112**. Data receiver **442** and data transmitter **440** are visible, as well as cross-sections B-B, C-C and D-D.

FIG. **7** is a schematic bottom view of pallet **100** in FIG. **3**. At least three holes **164** (seven shown) penetrate pallet bottom **112** to permit passage of long pins **204** (see FIG. **28**) – note that holes **164** must be outside outline **146** in order to prevent long pins **204** from striking FPDS **120**. A multiplicity of holes **166** also penetrate pallet bottom **112** to permit passage of short pins **206** (see FIG. **29**) – note that holes **166** must be within outline **146** to ensure that short pins **206** will lift FPDS **120**.

Holes **164** are at distances **150** and **152** from the four corners of pallet bottom **112** and three other holes **164** are spaced midway along three sides of pallet bottom **112**. It is not necessary to place a hole **164** in the left side of pallet bottom **112** since there is no corresponding long pin **204** on the left side of the pin plate (see FIG. **18**). The exact number and placement of holes **164** (and the corresponding pins **204** in pin plate **202**) is not critical to the pallet disassembly operation (see FIGS. **27-30**) – it is only important to have sufficient holes **164** (and long pins **204**) to lift pallet top **110** without slippage or instability without interfering with the ability to insert a robot end effector between pallet top **110** and pallet bottom **112** during FPDS removal/insertion (see FIGS. **31-33**). The X-Y spacings **160** and **162**, respectively, of holes **166** must be close enough to ensure minimal sagging of an FPDS between pins **206** as explained in FIG. **30**. Cross-section E-E is also illustrated in FIG. **7**.

FIG. **8** is a schematic view through section A-A of pallet **100** in FIG. **4** with dimensions perpendicular to FPDS **120** exaggerated. Pallet top **110** has a downward-facing lip which enables pallet top **110** to clamp FPDS **120** (shown exaggerated in thickness) down against the upper center surface of pallet bottom **112**. For proper operation of the alignment procedure shown in FIGS. **39A-39B**, it is preferred that the upper surface **129** of pallet bottom **112** (which comes into contact with the undersurface of FPDS **120**) have sufficient friction to prevent slippage between FPDS **120** and pallet bottom **112** when pallet top **110** is being moved relative to pallet bottom **112**. Pallet top **110** fits loosely over pallet bottom **112** to allow for small X-Y-Yaw displacements of pallet top **110** relative to pallet bottom **112** in order to align contactors **425** in pallet top **110** with test pads **426** (see FIG. **17**) on FPDS **120** (see FIGS. **39A-39B**). Openings **111** contain internal drive electronics and wiring necessary for electrical biasing of FPDS **120** (see FIGS. **13-16**). Cross-members **116** may also contain wiring (not shown) allowing for additional contactors along the Y-axis edges of the FPDs on the FPDS.

FIG. **9** is a schematic view through section E-E of pallet **100** in FIG. **7**, with dimensions perpendicular to FPDS **120** exaggerated. Openings **111** contain internal drive electronics and wiring necessary for electrical biasing of the FPDS **120** (see FIGS. **13-16**). Openings **113** in cross-members **114** contain wiring (not shown) connecting to contactors **425** (see FIG. **16**). Holes **164** and **166** penetrate pallet

bottom **112** to permit passage of pins **204** and **206**, respectively, on pin plate **202** (see FIGS. **28-29**).

INTERNAL STRUCTURE AND ELECTRONICS OF THE PALLET

FIG. **10** is a schematic diagram of the electronics within pallet **100**, data circuits to/from pallet **100**, and an inductive power transfer system. Pallet **100** contains internal drive electronics **410** which provides control voltages through control lines **423** to contactors **425**. These control voltages bias the source and gate connections to the TFTs on the FPDS as is familiar to those skilled in the art of FPDS testing – see U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein.

Contactors **425**, which typically can be "POGO" pins or some other type of spring-loaded contactor, make contact with test pads **426** on the surface of FPDS **120**. Test pads **426** are connected to shorting bars (not shown) on FPDS **120** by traces **427**. Control of internal drive electronics **410** is effected through a first data link comprising data line **498** from system control **1203** (see FIG. **2**), data transmitter **554**, signal beam **556**, data receiver **442**, and input signal line **430**. Internal drive electronics **410** communicates with system control **1203** (see FIG. **2**) by means of a second data link comprising output data line **431**, data transmitter **440**, signal beam **557**, data receiver **555**, and data line **499** to system control **1203** (see FIG. **2**). Internal data bus **422** includes signal lines **430** and **431**.

Internal drive electronics **410** are powered through an inductive power transfer system (IPTS) wherein the components outside pallet **100** comprise ac power supply **400** and primary transformer coil **402** which may be mounted within dual loadlock **575** and/or within pallet elevator **629** (first embodiment - see FIGS. **41-44**) or within dual loadlock **899** (second embodiment - see FIGS. **65-66**). The components of the IPTS within pallet **100** comprise secondary transformer coil **404**, battery charger **406**, wires **420** to charge battery **408**, and pallet dc power lines **421** to internal drive electronics **410**. Internal drive electronics **410** are powered by battery **408** at all times, but battery **408** is recharged only when pallet **100** is out of process chamber **522** (FIGS. **41-42**), or out of process chamber **804** (FIGS. **65-66**). It is desirable to maximize the magnetic flux coupling efficiency between primary coil **402** and secondary coil **404** to minimize the amount of stray magnetic flux which can have a

negative effect on the operation of columns **1211** in FIG. **2**. Methods of maximizing the flux coupling are well known to those skilled in the art. One such method is the use of a first core inside coil **402** with two pole faces positioned opposite two pole faces in a second core inside coil **404**. Magnetic shielding can be placed around coils **402** and **404** to reduce stray magnetic field generation further.

FIG. **11** is a schematic diagram of the electronics within pallet **100**, data circuits to/from pallet **100**, and a radiative power transfer system. All data links and connections are the same as for FIG. **10**. FIG. **11** differs from FIG. **10** only in the use of a radiative power transfer system (RPTS) to charge battery **408.** Light transmitter **479** radiates a strong light beam **478** to photocell **497** mounted on the exterior of pallet **100.** Photocell **497** generates a dc current which is fed through wires **470** to battery charger **471**, which charges battery **408** through wires **472**. The main advantage of an RPTS over the IPTS in FIG. **10** is the lack of stray magnetic field generation which could allow the RPTS to operate within process chamber **522** (FIGS. **41-42**) or process chamber **804** (FIGS. **65-66**). The main disadvantage of the RPTS is potentially less efficient power transfer due to the relatively low efficiency of photocells relative to transformers.

FIG. **12** is a schematic diagram of the electronics within pallet **100**, data circuits to/from pallet **100**, and a dual roller power transfer system. All data links and connections are the same as for FIGS. **10** and **11**. FIG. **12** differs from FIGS. **10** and **11** only in the use of a dual roller power transfer system (DRPTS) to charge battery **408**. Power supply **489** supplies an ac or a dc voltage difference through wires **484** to rollers **487** and **488** which roll along two contact strips **485** and **486**, respectively, on the exterior of pallet **100**. The voltage difference picked up between power strips **485** and **486** is fed through wires **483** to battery charger **482**, which charges battery **408** through wires **480**. The main advantage of a DRPTS over the IPTS in **FIG. 10** is the lack of stray magnetic field generation which could allow the RPTS to operate within the process chamber. The main disadvantage of the DRPTS is the need for physical contact to pallet **100** which may involve reliability issues, in particular relating to the need to keep the contact strips **485** and **486** and rollers **487** and **488** clean enough to provide good electrical contact. A variant of the configuration shown in FIG. **12** would place rollers **487** and **488** on pallet **100** and contact strips **485** and **486** outside pallet **100**.

FIG. **13** is a schematic view through section B-B in FIG. **6** showing the inductive power transfer system from FIG. **10**. External ac power supply **400** drives primary transformer coil **402**. The magnetic field generated by coil **402** passes through secondary coil **404**, thereby generating an ac voltage which is conducted to battery charger **406** which rectifies the ac voltage to a dc voltage used to charge battery **408** through connections **420**. Battery **408** powers internal drive electronics **410** by means of power circuit **421**. It is important that power connections **421** be coaxial cables or twisted pairs to avoid the generation of external magnetic fields during FPDS testing. Primary coil **400** can be mounted in pallet elevator **629** and/or dual loadlock **575** (first embodiment – FIGS. **41-42**) or dual loadlock **899** (second embodiment – FIGS. **65-66**) and would be used only when the pallet is not in either process chamber **522** (FIGS. **41-42**) or process chamber **804** (FIGS. **65-66**) – this avoids possible problems with the ac magnetic field between coils **402** and **404** potentially deflecting the electron beams used for FPDS testing. A preferred embodiment would include two iron cores, one within coil **402** and the other core within coil **404** with opposing pole faces to minimize field leakage. This method is familiar to those skilled in the art. Alternative methods of transferring power to the pallet are possible, as described in FIGS. **11** and **12**. The key requirement is that all transfer of power to the pallet must cause no negative effects on the FPDS testing process – this requires a battery on-board the pallet to power the internal drive electronics **410** between charging cycles. Since the pallet is exposed to vacuums in the loadlock and process chamber in the range of ~10^{-6} torr, it is necessary that battery **408** and internal drive electronics **410** be vacuum compatible (i.e., demonstrate minimal outgassing) and also that battery **408** not explode or be damaged due to internal pressure when in the vacuum. The X-Y dimensions **130** and **132** (FIG. **4**) of pallet **100** must be larger than the X-Y dimensions of FPDS **100** in order to accommodate battery charger **406**, battery **408**, and internal drive electronics **410**, which are housed in opening **111** around the perimeter of pallet top **110** as shown. To simplify the figure, the internal data bus and connections between internal drive electronics **410** and pallet **100** are not shown in FIGS. **13** and **14** (see FIGS. **15** and **16**).

FIG. **14** is a schematic view through section F-F in FIG. **4** of pallet **100** showing the internal power system of pallet **100** in FIG. **10**. All of the electronics shown in FIGS **13-16** is in pallet top **110**.

FIG. **15** is a schematic view through section C-C showing the internal data bus of pallet **100** in FIG. **6**. Data receiver **442** is a sensor for whatever type of radiation is used for beam **556** (FIG. **10**). Similarly, data transmitter **440** is a sensor for whatever type of radiation is used for beam **557** (FIG. **10**). Both data receiver **442** and data transmitter **440** are used to communicate between system control **1203** (FIG. **2**) and pallet **100** as illustrated in FIGS. **2** and **10-12**. Communication between data receiver **442**, data transmitter **440** and internal drive electronics **410** is by way of internal data bus **422**, contained in channel **111**, which must not generate any external magnetic fields that could affect the electron beams used for FPDS testing. In addition, internal data bus **422** must be immune to external RF interference.

FIG. **16** is a schematic view through section D-D showing connections **423** between internal drive electronics **410** and contactors **425** within pallet **100** in FIG. **6**. For clarity, contactors **425** are shown outside cross-members **114** – in reality, contactors **425** would be inside cross-members **114** (see FIG. **17**) and inside the outer perimeter of pallet top **110**. Additional contactors (not shown) could also be within cross-members **116**. Pallet **100** must be fabricated to provide adequate stiffness to assure that all contactors **425** make good electrical contact with test pads **426** on FPDS **120** – if POGO pins are used for contactors **425**, each pin will exert an upward force on pallet top **110** of at least a few g (force), adding up to sizeable total upward forces in the case of large numbers of POGO pins.

FIG. **17** is schematic detail view **121** with cutaway **428** showing contactors **425** within pallet **100** connecting to test pads **426** on FPDS **120** in FIG. **3**. As shown in FIGS. **10-12** and **16**, the voltages on contactors **425** are driven by internal drive electronics **410** within pallet top **110**. Contactors **425** are spring-loaded downwards against test pads **426**, typically with forces of at least a few g. Test pads **426** connect to traces **427**, which it turn connect to shorting bars (not shown) on FPDS **120** as explained in FIG. **1**. The design of pallet **100** implements a one-to-one mapping between contactors **425** in pallet top **110** and test pads **426** on FPDS **120**. Precise alignment of contactors **425** with test pads **426** is desirable in order to preserve this one-to-one mapping so that all test pads **426** receive the necessary

bias voltages – the procedure illustrated in FIGS. **34-39B** implements a procedure to accomplish contactor-to-test pad alignment across the entire surface of FPDS **120** simultaneously.

PIN PLATE AND ROBOT END EFFECTOR DESIGN

FIG. **18** is a schematic isometric view of pallet **100** and pin plate **202**, illustrating the insertion direction **208** for pin plate **202** to enter pallet **100**. Pallet **100** is comprised of pallet top **110** and pallet bottom **112**, with provision for FPDS **120** to be clamped between them. As is shown in detail in FIGS. **27-30**, long pins **204** fit through holes **164** in pallet bottom **112** (see FIG. **7**) to lift pallet top **110** off FPDS **120** and off pallet bottom **112**. Similarly, short pins **206** fit through holes **166** in pallet bottom **112** (see FIG. **7**) to lift FPDS **120** off pallet bottom **112**.

FIGS. **19-21** are schematic top, side and end views of pallet **100** and pin plate **202** in FIG. **18**, respectively. FIG. **19** has a partial cutaway to show pin plate **202** beneath pallet **100**. In FIGS. **20** and **21**, the vertical scales (perpendicular to the plane of pallet **100**) of both pallet **100** and pin plate **202** are exaggerated for clarity. The locations of pins **204** and **206** must match the locations of holes **164** and **166** (see FIG. **7**), respectively. The diameters of pins **204** and **206** should be large enough to prevent bending or buckling when supporting the weights of pallet top **110** and FPDS **120**, respectively (see FIG. **30**). The diameters of holes **164** and **166** (see FIG. **7**) should allow some clearance with pins **204** and **206**, respectively, to enable X-Y-Yaw alignment of pallet top **110** with pallet bottom **112**, as shown in FIGS. **39A-39B**. The lengths **288** of pins **206** must be sufficient to raise FPDS **120** far enough above pallet bottom **112** to allow room for robot end effector **243** (see FIG. **31**) to fit between FPDS **120** and pallet bottom **112**. The lengths **284** of pins **204** must be enough longer than the lengths **288** of pins **206** to allow FPDS **120** to be lifted off pins **206** by robot end effector **243** (see FIG. **32**).

FIG. **22** is a schematic isometric view of a robot end effector **243** attached to end effector mount **240**. End effector **243** is equivalent to end effectors **731-733** (FIGS. **61-63**) and end effectors **831-832** (FIGS. **67-69**). End effector mount **240** is equivalent to end effector mounts **730** (FIGS. **61-63**) and **830** (FIGS. **67-69**).

FIG. **23** is a schematic top view of robot end effector **243** and end effector mount **240** in FIG. **22**. End effector **243** is comprised of end effector bars **242** and

end effector bars connector **321**. Dimension **301** is preferably greater than the length of an FPDS to ensure that the FPDS is fully supported during FPDS transport. The purpose of slots **306** is to allow end effector **243** to fit between short pins **204** on pin plate **202** (see FIG. **19**). The widths **305** of slots **306** between end effector bars **242** must be larger that the diameters of short pins **206** but not so large that an FPDS can sag excessively between end effector bars **242**. The sum of the widths **304** and **305** must equal the Y-axis spacing of short pins **206** (which must match the Y-axis spacing **162** of holes **166** – see FIG. **7**).

FIG. **24** is a schematic side view of robot end effector **243** and end effector mount **240** in FIG. **22**. The thickness **306** of end effector **243** (which is the thickness of end effector bars **242**) must be adequate to prevent excessive sagging of end effector bars **242** under their own weight plus the weight of an FPDS being transported. "Excessive sagging" here is any amount of sagging which may result in damage to the FPDS being transported or which would interfere with the FPDS exchange process (see FIGS. **61-63** and **67-69**).

FIG. **25** is a schematic end view of robot end effector bars **242** and end effector mount **240** in FIG. **22**. Dimension **302** is preferably as wide as possible to give maximum support to the FPDS being transported while still fitting between long pins **204** along the two long sides of pin plate **202** (see FIG. **19**).

DETAILED PALLET DISASSEMBLY PROCEDURE

FIGS. **26-33** show various views of pin plate **202** disassembling a pallet. This process occurs within pallet elevator **629** in the first embodiment of the present invention shown in FIGS. **41** and **42**, and within dual loadlock **899** in the second embodiment shown in FIGS. **65** and **66**. Note that pin plate **202** is shown simplified – the trenches to allow clearance for the bi-directional motor-driven rollers are omitted for clarity, as are the rollers themselves.

FIG. **26** is a schematic isometric cutaway view of pin plate **202** disassembling a pallet (including pallet top **110** and pallet bottom **112**, with provision for FPDS **120** to be clamped between them). Cutaway **323** of pallet top **110** reveals internal spaces **111** and **113** for internal drive electronics **410** and wiring (not shown – see FIGS. **13-16**). Cutaway **322** of FPDS **120** reveals robot end effector **243** (attached to end effector mount **240**) supporting FPDS **120**. Cutaway **321** of robot end effector

243 (comprised of end effector bars **242** and end effector bars connector **321**) reveals pallet bottom **112** as well as short pins **206** and long pins **204** on pin plate **202** protruding through holes **166** and **164**, respectively (see FIG. **7**), in pallet bottom **112**. At the upper right, a long pin **204** can be seen supporting the edge of pallet top **110**. Cutaway **320** in pallet bottom **112** reveals pin plate **202** underneath, showing a few short pins **206** and a long pin **204** at the corner of pin plate **202** at the center front in FIG. **26**.

FIGS. **27-30** show the sequence of steps by which pin plate **202** disassembles pallet **100**, enabling already-tested FPDS **120** to be removed.

FIG. **27** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. Long pins **204** in pin plate **202** are aligned coaxially with, and ready for insertion into, holes **164** in pallet bottom **112**. Pin plate **202** starts moving upwards (arrow **210**) to begin the pallet **100** disassembly procedure.

FIG. **28** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. The pin plate actuator (not shown) has raised pin plate **202** to insert long pins **204** into holes **164**. The upper ends of long pins **204** are now making contact with undersurface **207** of pallet top **110**. Pallet **100** is still assembled at this point. Pin plate **202** continues moving upwards (arrow **212**).

FIG. **29** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. The pin plate actuator (not shown) has raised pin plate **202** an additional distance upwards from FIG. **28**, lifting pallet top **110** off FPDS **120**. The upwards motion of pin plate **202** has also inserted short pins **206** into holes **166**. The upper ends of short pins **206** are now making contact with undersurface **216** of FPDS **120**. Pin plate **202** continues moving upwards (arrow **214**).

FIG. **30** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. The pin plate actuator (not shown) has raised pin plate **202** an additional distance upwards from FIG. **29**, lifting pallet top **110** farther away from pallet bottom **112** – note that pallet top **110** is the same distance above FPDS **120** as in FIG. **29**. The upwards motion of pin plate **202** has also lifted FPDS **120** off pallet bottom **112**. Upwards motion of pin plate **202** ceases at this point.

FIGS. **31-33** show the sequence of steps by which a robot, having an end effector **243** and end effector mount **240**, removes an already-tested FPDS **120** from a disassembled pallet. End effector **243** is equivalent to end effectors **731-733** in the

three-blade robot shown in FIGS. **61-63** or to end effectors **831-832** in the two-blade robot shown in FIGS. **67-69**.

FIG. **31** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. End effector **243** is moving in (arrow **244**) under FPDS **120** and above pallet bottom **112**. It is important that spacing **299** between the under surface of FPDS **120** and the upper surface of pallet bottom **112** is wide enough to accommodate the thickness **306** (FIG. **24**) of end effector **243** in order to avoid striking (and possibly damaging) FPDS **120** and/or pallet bottom **112**.

FIG. **32** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. End effector **243** is moving up (arrow **246**) to lift FPDS **120** off short pins **206** on pin plate **202**. Relative lengths **284** and **288** of long pins **204** and short pins **206**, respectively, (see FIG. **20**) must be chosen to ensure adequate clearance for end effector **243** to lift FPDS **120** and exit from the disassembled pallet without dragging the upper surface of FPDS **120** along the under surface of pallet top **110**, thereby possibly damaging FPDS **120** and/or pallet top **110**.

FIG. **33** is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. **19**. End effector **243** is withdrawing (arrow **250**) FPDS **120** from the disassembled pallet.

The reverse process from that shown in FIGS. **27-33** is used to insert an FPDS **120** for testing into pallet **100**:

1) FIG. **33**: End effector **243** carries (arrow **250** reversed) FPDS **120** into disassembled pallet **100**.
2) FIG. **32**: End effector **243** lowers (arrow **246** reversed) FPDS **120** onto short pins **206** on pin plate **202**.
3) FIG. **31**: End effector **243** withdraws (arrow **244** reversed) from disassembled pallet **100**.
4) FIG. **30**: Pin plate **202** is ready to begin reassembling pallet **100**.
5) FIG. **29**: Pin plate **202** has lowered (arrow **214** reversed) FPDS **120** onto pallet bottom **112**.
6) FIG. **28**: Pin plate **202** has lowered (arrow **212** reversed) pallet top **110** onto FPDS **120** and onto pallet bottom **112**, clamping FPDS **120** between pallet top **110** and pallet bottom **112**.

7) FIG. **27**: Pin plate **202** actuator has lowered (arrow **210** reversed) far enough to remove long pins **204** and short pins **206** completely from holes **164** and **166**, respectively, in pallet bottom **112**. At this point, pallet **100** has been reassembled, clamping an untested FPDS **120** between pallet top **110** and pallet bottom **112**, ready for alignment of pallet top **110** to FPDS **120** (see FIGS. **34-39B**), followed by e-beam testing.

PROCEDURE FOR ALIGNING THE PALLET TOP TO THE FPDS

FIG. **34** is a schematic detail view **122** showing a capacitive sensor **1002** attached to pallet top **110** detecting the location of a passivated alignment mark **1001** on FPDS **120** in FIG. **3**. An FPDS has a number of alignment marks **1001**, typically with a "+" shape. In order to make good electrical contact between the contactors **425** in pallet top **110** and test pads **426** on FPDS **120** (see FIG. **17**), in general it will be necessary to adjust the position of pallet top **110** relative to FPDS **120**. The upper center surface of pallet bottom **112** is made from a material, such as rubber, which prevents FPDS **120** from sliding relative to pallet bottom **112**. Thus, if pallet top **110** is moved a certain amount relative to pallet bottom **112**, it will move the same amount relative to FPDS **120**. FIGS. **39A-39B** illustrate a method for accomplishing relative motion between pallet top **110** and pallet bottom **112**. It is not possible to make direct electrical connection to alignment mark **1001** because at this stage in the manufacturing of FPDS **120**, alignment mark **1001** is already covered by an insulating passivation layer. Because what is important is the alignment between contactors **425** (which are part of pallet top **110**) and test pads **426** (which are part of FPDS **120** – see FIG. **17**), it is necessary to mount capacitive sensor **1002** on pallet top **110** so that the alignment mechanism shown in FIGS. **39A-39B** serve to move both contactors **425** and capacitive sensor **1002** together.

FIG. **35** is a schematic view of capacitive sensor **1002** and its associated electronics, with detail **122** shown as an inset. Capacitive sensor **1002** is shown with 25 individual sensing elements **1011**, in a 5 x 5 array. The electrical circuits shown connected to one sensing element **1011** are identical to circuits (not shown) which would be connected to the other 24 sensing elements. The method used here to detect the position of alignment mark **1001** is capacitive sensing of the underlying

passivated mark – the mark itself is made from conducting material, so it will have a small capacitance which can be sensed by each of the 25 sensing elements. In FIG. **35**, alignment mark **1001** is shown aligned with capacitive sensor **1002** – thus the center of the "+" mark is under the center sensing element of the 5 x 5 array.

The square-wave relaxation oscillator circuit formed by op-amp **1013**, op-amp output **1021**, resistors **1014**, **1015**, and **1017**, capacitor **1018**, capacitance **1020** (arising from connection **1012** to sensing element **1011** and the ground connection **1019** to FPDS **120**), and summation node **1016** will be understood by those skilled in the art. In this oscillator, the voltage **1025** on output **1021** of op-amp **1013** swings back-and-forth between voltages near the op-amp **1013** power supply rails (not shown) at a frequency which is inversely proportional to the total capacitance of the parallel combination of capacitor **1018** and capacitance **1020** (the capacitance between sensing element **1011** and alignment mark **1001**). When a sensing element **1011** is over alignment mark **1001**, capacitance **1020** will be larger, increasing oscillation period **1026**; conversely, when a sensing element **1011** is not over alignment mark **1001**, capacitance **1020** will be smaller, decreasing oscillation period **1026**. Although it is not permitted for the undersurface of capacitive sensor **1002** to touch the upper surface of FPDS **120**, it is desirable to make the gap between capacitive sensor **1002** and FPDS **120** as small as possible to increase the variation in capacitance **1020**, thereby making the process for locating alignment mark **1001** more sensitive. The square wave **1025** on op-amp **1013** output line **1021** is the input to frequency meter **1010** which generates a time-varying frequency measurement **1029** which is a function of the distance between sensing element **1011** and alignment mark **1001**. The 25 parallel circuits combine to generate a 5 x 5 array of time-varying frequency measurements wherein the lowest frequencies (i.e., longest oscillation periods **1026**) indicate sensing elements **1011** which are directly over alignment mark **1001**, while higher frequencies correspond to sensing elements **1011** which are partially, or completely, off of alignment mark **1001**.

FIG. **36** shows an alignment mark **1034** underneath capacitive sensor **1002** in the case of FPDS misalignment. Table I shows the percent of overlap between various sensor elements **1011** and alignment mark **1034** in the case of misalignment between capacitive sensor **1002** and alignment mark **1034**.

0%	0%	0%	0%	0%
0%	25%	25%	0%	0%
25%	75%	75%	25%	0%
25%	75%	75%	25%	0%
0%	25%	25%	0%	0%

Table I. Sensor element **1011** signals for misalignment between capacitive sensor **1002** and alignment mark **1034**.

Comparison with Table II (for proper alignment) shows that the difference is substantial and provides a clear definition of the required displacement vector (i.e., the motion of pallet top **110** relative to FPDS **120**) which will correct the misalignment.

FIG. **37** shows alignment mark **1001** underneath capacitive sensor **1002** in the case of correct FPDS alignment. Table II shows the percent of overlap between various sensor elements **1011** and alignment mark **1001** in the case of proper alignment between capacitive sensor **1002** and alignment mark **1001**.

0%	0%	0%	0%	0%
0%	0%	100%	0%	0%
0%	100%	100%	100%	0%
0%	0%	100%	0%	0%
0%	0%	0%	0%	0%

Table II. Sensor element **1011** signals for alignment between capacitive sensor **1002** and alignment mark **1001**.

FIG. **38** shows detail view **123** (see FIG. **3**) of an alternative type of alignment mark detector using light optical illumination and imaging to find alignment mark **1001**. Note that each FPDS **120** has a number of identical alignment marks **1001**, distributed over the full area of FPDS **120** – the two alternative means for locating alignment marks shown in FIGS. **34-37** and in FIG. **38** are locating the same types of alignment marks **1001**. FIG. **3** shows both means within one pallet only for illustrative purposes – normally, a single pallet would have only one type of alignment mark detection means. Although alignment mark **1001** is underneath an insulating passivation layer, the passivation is nearly transparent so it is possible to

detect the location of alignment mark **1001** optically. Because what is important is the alignment between contactors **425** (which are part of pallet top **110**) and test pads **426** (which are part of FPDS **120** – see FIG. **17**), it is necessary to mount the optical sensor on pallet top **110** so that the alignment mechanism shown in FIGS. **39A-39B** moves contactors **425** and the optical sensor together. The optical sensor comprises imaging lens **1103**, optical transmission means **1102** (which may be a fiber optic or a prism combined with a light pipe), and an imaging sensor such as a CCD camera (not shown) – the design of optical sensors is familiar to those skilled in the art. An image of alignment mark **1101** is focused by lens **1103** through optical transmission means **1102** onto the imaging sensor, which generates an image of alignment mark **1101** – this image data is relayed to internal drive electronics **410** within pallet top **110**. Image processing functions within internal drive electronics **410** then analyze the image data to determine the location of alignment mark **1001** and the required displacement vector for pallet top **110** relative to FPDS **120** needed to correct any misalignment.

To fully characterize the misalignment between pallet top **110** and FPDS **120**, it is necessary to locate at least two alignment marks **1001** on FPDS **120**, preferably well separated to minimize errors. Given two or more required displacement vectors determined by imaging two or more alignment marks **1001** with either capacitive sensors **1002** (FIGS. **34-37**) or optical sensors (FIG. **38**), the alignment mechanism illustrated in FIGS. **39A-39B** can then used to correct the overall X-Y-Yaw misalignment between pallet top **110** and FPDS **120**. Recalling that pallet bottom **112** is designed to prevent slippage between FPDS **120** and pallet bottom **112**, any misalignment between pallet top **110** and FPDS **120** can be considered to require an X-Y-Yaw adjustment between pallet top **110** and pallet bottom **112** as shown by vectors **1151-1154** in FIG. **39A** – an X-Y coordinate system is defined by X-axis **1171** and Y-axis **1172**. Actuators **1151-1154** are controlled by internal drive electronics **410** in pallet top **110** (see FIGS. **13-16**). Detail **1155** is shown in FIG. **39B**.

FIG. **39B** is detail view **1155** with partial cutaway **1165** of X-Y-Yaw actuators mounted between pallet top **110** and pallet bottom **112**. Two actuators **1163** and **1164** are shown, with actuator **1163** acting generally parallel to X-axis **1171** and actuator **1164** acting generally parallel to Y-axis **1172**. Actuator **1163** is attached at

point **1160** to pallet top **110**, and at point **1162** to pallet bottom **112**. Actuator **1164** is connected to pallet bottom **112** at point **1162** and to pallet top **110** at point **1161** – thus actuators **1163** and **1164**, operating in tandem with two identical actuators at the diagonally opposite corner of pallet **100** (the corner with vectors **1151** and **1152**), can generate all three required alignment motions: parallel to X-axis **1171**, parallel to Y-axis **1172** and Yaw (rotation about an axis perpendicular to pallet **100**.

The placement of FPDS **120** on pallet bottom **112** by either the three-blade robot (the first embodiment) or the two-blade robot (the second embodiment) is important in determining the possible magnitude of misalignment between pallet top **110** and FPDS **112**. With a sufficiently precise robot motion mechanism, the range of possible misalignments can be kept <~1-2 mm in X and Y. The difference between the diameters of pins **204** and **206** (FIGS. **18-21**) and the diameters of holes **164** and **166** (FIG. **7**), respectively, determines the maximum range of correction for misalignments between pallet top **110** and FPDS **120**. Note that since pallet **100** is disassembled into pallet top **110** and pallet bottom **112** during the process for FPDS removal and replacement, actuators **1163** and **1164** must preferably be part of pallet top **110** (since pallet top **110** has all of the internal drive electronics **410** – see FIGS. **13-16**). Thus attachment point **1162** must be able to reliably disconnect from pallet bottom **112** during pallet disassembly (between FIGS. **28** and **29**). During the reverse process (going between FIGS. **29** and **28**, with arrow **214** reversed), attachment point **1162** must reconnect to pallet bottom **112**. It is not important that attachment point **1162** accurately reconnect within any tight tolerances since actuators **1163** and **1164** (as well as the corresponding actuators at the diagonally-opposite corner) can adjust for any positional nonreproducibilities). Once proper alignment between pallet top **110** and FPDS **120** has been achieved, it is necessary for pallet top **110** to be locked in position with respect to pallet bottom **112** (and thus be locked relative to FPDS **120**) - this locking mechanism (see FIG. **40**) is under control of internal drive electronics **410**. The design of X-Y-Yaw actuators for use as described herein will be understood by those skilled in the art upon reading the present disclosure.

FIG. **40** is a schematic detail view **124** with cutaway **1450** of a locking mechanism between pallet top **110** and pallet bottom **112** in pallet **100** in FIG. **3**. Magnetic plate **1452** is attached to pallet bottom **112**. Magnetic pole-piece **1451**,

with activating magnet coil **1453** is mounted within pallet top **110** (mounting not shown), roughly above magnetic plate **1452**. When current from internal drive circuits **410** (not shown – see FIG. **13**) flows through coil **1453**, an attractive magnetic field draws magnetic plate **1452** tightly against pole piece **1451**, thereby locking pallet top **110** to pallet bottom **112**. Magnetic plate **1452** is made somewhat larger than the opposing surfaces of pole piece **1451** to enable a certain amount of X-Y-Yaw adjustment of pallet top **110** relative to pallet bottom **112** without impairing the magnetic circuit formed by magnetic plate **1252** and pole piece **1451** – this enables the alignment procedure in FIGS. **34-39B** to operate without interfering with the locking mechanism between pallet top **110** and pallet bottom **112**. At least two locking mechanisms like that shown in view **124** would be necessary to securely lock pallet top **110** to pallet bottom **112** during pallet transfer and FPDS testing in the process chamber. It is important that the magnetic circuit design minimizes magnetic flux leakage to eliminate the possibility of interference with the electron beams used for testing. The design of locking mechanisms for use as described herein will be understood by those skilled in the art upon reading the present disclosure. The present invention also includes other methods of clamping the top and bottom together that will be apparent to those skilled in the art.

FIRST EMBODIMENT OF AN FPDS TESTING SYSTEM

The first embodiment of the present invention is an FPDS testing system comprising three main subsystems:

1) A pallet elevator **629**, which serves as the interface between the FPD fab and the FPDS testing system. The functions of pallet elevator **629** are the following:
    a. Enables a robot to transport FPDSs from the FPD fab into the FPDS testing system.
    b. Assembles pallets containing FPDSs (one per pallet) clamped between the pallet top and pallet bottom.
    c. Performs alignment between contactors in the pallet top and test pads on the FPDS.
    d. Assists in the transport of assembled and aligned pallets containing FPDSs ready for testing into the dual loadlock.

e. Assists in the transport of pallets with tested FPDSs back from the dual loadlock.

f. Disassembles pallets with tested FPDSs.

g. Enables the robot to transport tested FPDSs from the FPDS testing system to the FPD fab.

2) A dual loadlock **575**, comprising two loadlocks, each of which has the following functions:

a. Assists in the transport of pallets containing FPDSs for testing from the pallet elevator.

b. Pumps down to a vacuum level equal to that in the process chamber.

c. Assists in the transport of one pallet at a time into the process chamber for e-beam testing.

d. Assists in the removal of one pallet at a time from the process chamber after e-beam testing.

e. Vents to atmospheric pressure.

f. Assists in the transport of pallets containing tested FPDSs back to the pallet elevator.

3) A process chamber **522**, which has the following functions:

a. Assists in the transport of one pallet at a time from the dual loadlock.

b. Tests for defective pixels on the FPDS in the pallet using one or more electron beams.

c. Assists in the transport of one pallet at a time back into the dual loadlock after testing.

FIG. **41** is a top view of a first embodiment of an FPDS testing system embodying the present invention, including pallet elevator **629**, dual loadlock **575**, and process chamber **522**. Pallet elevator **629** serves as the interface between the FPD fab and the multiple e-beam FPDS testing system, and is always at atmospheric pressure. Dual loadlock **575** has two separate loadlocks which cycle between atmospheric pressure and the vacuum level in process chamber **522**, typically ~10^{-6} torr. Process chamber **522** remains at ~10^{-6} torr at all times during

testing – it is vented to atmosphere only for maintenance. Valve **506** enables insertion/removal of pallets to/from upper loadlock **502** (see FIG. **43**) in dual loadlock **575**. Cross-section H-H is also illustrated in FIG. **41**.

FIG. **42** is a schematic side view of the FPDS testing system in FIG. **41**. Valves **506** and **507** enable insertion/removal of pallets to/from upper **502** and lower **505** loadlocks, respectively (see FIG. **43**), in dual loadlock **575**. Dual loadlock **575** sits on supports **714** which provide vertical motion capability for dual loadlock **575** to enable the two-way transfer of pallets: 1) out of process chamber **522** going into any slot in dual loadlock **575**, and 2) out of any slot in dual loadlock **575** going into process chamber **522** (see FIGS. **51-58**). Pallet elevator **629** sits on supports **710** which provide vertical motion capability for pallet elevator **629** to enable the two-way transfer of pallets: 1) out of any slot in dual loadlock **575** going into any slot in pallet elevator **629**, and 2) out of any slot in pallet elevator **629** going into any slot in dual loadlock **575** (see FIGS. **51-58**). Note that supports **710** must also move pallet elevator **629** vertically to track the motion of dual loadlock **575**. Process chamber **522** sits on fixed supports **718**. Supports **710**, **714**, and **718** preferably should provide vibration isolation to pallet elevator **629**, dual loadlock **575** and process chamber **522**, respectively, to ensure that there is minimal vibration of pallet **500** relative to optics assembly **520** (FIG. **43**). A description of the operation of the dual loadlock **575** and process chamber **522** is provided in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein. Cross-section G-G is also illustrated in FIG. **19**.

FIG. **43** is a schematic view of section H-H of FIG. **41** of the FPDS testing system (pallet elevator **629** is not shown). Dual loadlock **575** is comprised of upper loadlock **502** and lower loadlock **505**. A closed valve (such as valves **506** and **517**) is indicated by an "X", while an open valve (such as valves **507**, **516**, and **518**) has no "X". Two sets of bi-directional motor-driven rollers **623** and **624** define two storage slots in upper loadlock **502**, and another two sets of bi-directional motor-driven rollers **625** and **626** define two storage slots in lower loadlock **505**. Rollers **623-626** have three functions:

1) Supporting pallets within dual loadlock **575** – each set of rollers **623-626** defines a separate pallet storage slot within dual loadlock **575**.

2) Assisting in transferring pallets to/from dual loadlock **575** from/to pallet elevator **629** (working in conjunction with one of the three sets of bi-directional motor-driven rollers **620-622** in pallet elevator **629** – see FIGS. **51-58**).

3) Assisting in transferring pallets to/from dual loadlock **575** from/to process chamber **522** (working in conjunction with bi-directional motor-driven rollers **627** in process chamber **522**).

A pallet **500** is shown being transported (arrow **530**) under optics assembly **520** by two sets of bi-directional motor-driven rollers: rollers **623** in upper loadlock **502**, and rollers **627** in process chamber **522**. Upper loadlock **502** has two slit valves: valve **506** allowing insertion/removal of pallets into/from dual loadlock **575** from/into pallet elevator **629**, and valve **516** allowing insertion/removal of pallets into/from process chamber **522.** Valve **518** (which normally remains open) enables process chamber **522** to be sealed off from dual loadlock **575** for maintenance on either dual loadlock **575** or process chamber **522**. Optics assembly **520** includes both the linear array of electron columns **1211** and the linear array of corresponding detectors **1240** (see FIG. **2**). An electron beam testing procedure for FPDSs is discussed in detail in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 and is incorporated by reference herein.

During the time required to test the FPDSs in pallets **500** and **501**, the present invention provides for removal of two pallets containing already-tested FPDSs (not shown) through valve **507** from lower loadlock **505**. Two pallets **503** and **504** with FPDSs ready for testing can then be inserted into lower loadlock **505**. In FIG. **43,** valve **507** is ready to be closed (valve **517** is already closed) and lower loadlock chamber **505** will then be pumped down to the same pressure as in process chamber **522** (typically ~10^{-6} torr).

After testing of the FPDSs in pallets **500** and **501**, valve **516** is closed while dual loadlock **575** indexes up to enable pallets from lower loadlock **505** to be inserted into process chamber **522** through open valves **517** and **518.** The same testing procedure described above for pallets **500** and **501** is then followed for pallets **503** and **504**. During e-beam testing, pallet **503** is supported and transported by bi-directional motor-driven rollers **625** and **627**, and pallet **504** is supported and transported by bi-directional motor-driven rollers **626** and **627**. During the time

required to test the FPDSs in pallets **503** and **504**, upper loadlock **502** is vented to atmosphere and pallets **500** and **501** are removed and replaced with two pallets containing FPDSs ready for testing (not shown), followed by a pump-down of upper loadlock **502** to the same pressure as in process chamber **522** (typically ~10^{-6} torr).

This procedure of toggling between testing FPDSs from the upper and lower loadlocks enables high system throughput since there is always one loadlock (either upper loadlock **502** or lower loadlock **505**), pumped down and ready to insert pallets into process chamber **522** for testing by optics assembly **520**. All other operations, such as loadlock pumpdown and venting, pallet assembly/disassembly, pallet top-to-FPDS alignment, and pallet insertion/removal into/from the dual loadlock are performed in parallel with e-beam testing and thus have no effect on system throughput.

FIG. **44** is a schematic view through section G-G of the FPDS testing system in FIG. **42**. Pallet elevator **629** is shown ready to supply pallet **628**, loaded with an untested FPDS, for insertion into double loadlock **575**. FIGS. **51-58** show schematic views of the pallet insertion/removal process between pallet elevator **629** and dual loadlock **575**. Optics assembly **520** extends across the full width of pallet **500** to enable testing of all pixels on the FPDS in pallet **500** without the need for sideways (vertical in FIG. **44**) motion of pallet **500**.

PALLET X-Y-YAW POSITIONAL MEASUREMENT SYSTEM

FIGS. **45-47** show three schematic views through section G-G of the FPDS testing system (pallet elevator **629** and bi-directional motor-driven rollers **623-627** not shown for clarity) of FIG. **42** showing a method for measurement of the X-Y-Yaw position of pallet **572** within process chamber **522**. Optics assembly **520** is cut away at both ends to show laser beams **570** and **571**. The coordinate system consists of X-axis **573** and Y-axis **574**. The position of pallet **572** along X-axis **573** is measured using sensors **550** and **551**, which can be laser interferometers, laser triangulators, or some other non-contact means of distance measurement sufficiently accurate to meet the positioning requirements dictated by the testing process performed by optics assembly **520**. For e-beam FPDS testing, the positional measurement accuracy requirement is ~2-10 μm, substantially smaller than the dimensions of test pads **426** (see FIG. **17**). FIGS. **45-47** illustrate the use of laser positional

measurement of pallet **572**, where laser beam **568** is emitted by a laser within sensor **550** towards a reflecting surface on the side of pallet **572**. Beam **568** then reflects off the side of pallet **572** back to a detector within sensor **550**. Either through optical interference or by triangulation, sensor **550** can then determine the distance between sensor **550** and the reflecting side of pallet **572**. The same positional measurement process occurs for sensor **551** emitting beam **569**, sensor **552** emitting beam **570**, and sensor **553** emitting beam **571**. Sensors **550** and **551** detect both X-axis and Yaw motion as illustrated in FIGS. **48** and **50**. Sensors **552** and **553** measure the position of pallet **572** along Y-axis **574** as shown in FIG. **49**.

As discussed in FIGS. **10-12**, control of internal drive electronics **410** is effected through a first data link comprising data transmitter **554**, signal beam **556**, and data receiver **442**. Feedback from internal drive electronics **410** within pallet **572** is effected by a second data link comprising data transmitter **440**, signal beam **557**, and data receiver **555**. It is necessary that pallet **572** not undergo yaw motions **608** (see FIG. **50**) large enough to misalign signal beam **556** with receiver **442**, or signal beam **557** with receiver **555** – in general this requirement should not be difficult to meet, since positional errors of pallet **572** can be kept <1-2 mm through careful design of bi-directional motor-driven rollers **623-627** as is familiar to those skilled in the art. Since the overall dimensions **130** and **132** (FIG. **4**) of pallet **572** are typically ~2-3 m, positional errors of ~1-2 mm will induce Yaw angles <1 mrad.

Sensors **550-553** must have the capability to track the position of pallet **572** sufficiently quickly to keep up with the pallet velocities required by the testing process performed by optics assembly **520**. From the timelines in FIGS. **64** and **70**, 40 s is typically allotted for alignment and testing – thus, with a 3 m pallet, the pallet velocity during testing would be: (3000 mm)/(40 s) = 75 mm/s. Only 10 s is allotted for pallet removal in FIGS. **64** and **70**, so the pallet removal velocity would be 4x higher: (3000 mm)/(10 s) = 300 mm/s. Commercially-available laser position sensors are capable of positional measurement at these velocities as is familiar to those skilled in the art.

In FIG. **45**, e-beam testing has just begun, thus pallet **572** is just entering process chamber **522**. In FIG. **46**, e-beam testing is about half completed, thus pallet **572** is now half way into process chamber **522**. In FIG. **47**, e-beam testing is nearly complete, thus pallet **572** has moved almost entirely into process chamber

522. Comparison of FIGS. **45-47** shows that beams **568** and **569** strike nearly the same areas on the end of pallet **572**, regardless of the X-position of pallet **572**. Thus, only two small reflective areas (at the impact points of beams **568** and **569**) are needed on the end of pallet **572**. Beams **570** and **571** strike various positions along the entire length of pallet **572** as seen in FIGS. **45-47** – this requires that both sides of pallet **572** be reflective over their entire lengths for proper operation of sensors **552** and **553**. One benefit of having two Y-axis sensors **552** and **553** is redundancy – if either of sensors **552** or **553** fails to provide a distance measurement due to imperfections in the reflectivity of the pallet side, the other sensor will maintain measurement continuity.

FIGS. **48-50** show three schematic views through section G-G of the FPDS testing system of FIG. **42** (pallet elevator **629** and bi-directional motor-driven rollers **623-627** not shown for clarity) showing positional errors along the X-axis (FIG. **48**), Y-axis (FIG. **49**), and Yaw (FIG. **50**).

In FIG. **48**, pallet **600** is shown with an offset in the direction **602** from its desired position **601** along the X-axis **573** (parallel to the pallet direction of travel). X-axis positional errors are detected when sensors **550** and **551** show errors with both the same magnitude and the same sign.

In FIG. **49**, pallet **603** is shown with an offset in the direction **605** from its desired position **604** along the Y-axis **574** (perpendicular to the pallet direction of travel). Y-axis positional errors are detected when sensors **552** and **553** show positional errors with the same magnitude and opposite signs.

In FIG. **50**, pallet **606** is shown with a Yaw **608** (rotation about a vertical axis) offset from its desired orientation **607**. Yaw positional errors are detected when sensors **550** and **551** show errors with the same magnitude but with opposite signs.

As shown in FIG. **2**, the four position sensors **550-553** are connected to X-Y-Yaw readout **1202**, which, given the four position measurements from sensors **550-553**, calculates X-Y-Yaw positional errors, which are sent to system control **1203** over control link **1219**. System control **1203** then transmits the X-Y-Yaw positional error data to two subsystems:

1) Over control link **1220** to optics control **1201**, which then deflects beams **1230** to correct for positional errors. This enables the FPDS testing system to move pallet **100** at an approximately constant speed

under the linear array of columns **1211**, without the requirement for extremely accurate control of the speeds of bi-directional motor-driven rollers **627**. Further details of column **1211** are provided in FIG. **71**.

2) Over data line **498** to data transmitter **554**, to be sent (using beam **556**) to data receiver **442** on pallet **100** to enable internal drive electronics **410** (see FIG. **13**) to determine which voltages should be sent to various contactors **425**. This is necessary because the location of pallet **100** relative to electron columns **1211** (the X-Y-Yaw positional data) determines which pixels are located under electron beams **1230**, and thus can be tested at any particular time.

PALLET TRANSFER BETWEEN PALLET ELEVATOR, DUAL LOADLOCK AND PROCESS CHAMBER

FIGS. **51-57** are schematic views through section H-H of the FPDS testing system of FIG. **41** showing three simultaneous processes at various points in time:

1) Electron-beam testing by optics assembly **520** of an FPDS in pallet **600** from upper loadlock **502** which is at the same pressure (~10^{-6} torr) as processing chamber **522**.
2) Removal of pallets **602** and **603** with already-tested FPDSs from lower loadlock **505** which is at atmospheric pressure.
3) Insertion of pallets **604** and **605** with FPDSs ready for testing into lower loadlock **505** which is at atmospheric pressure.

FIG. **58** is the same view, shown at 120 s after FIG. **51**. Pallet elevator **629** is simplified for clarity by omission of pin plates **705-707** (see FIGS. **59-63**).

FIG. **51** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. During testing, pallet **600** is supported and moved into/out of process chamber **522** by bi-directional motor-driven rollers **623** and **627**. Simultaneously, processed pallet **602** is being removed (arrow **611**) from lower loadlock **505** through open valve **507** into pallet elevator **629**. Pallet **602** is being supported and moved out of lower loadlock **505** by bi-directional motor-driven rollers **622** and **625**. Pallets **604** and **605** are ready for insertion into lower loadlock

505. Pallet elevator **629** contains three storage slots defined by bi-directional motor-driven rollers **620-622**. Since upper loadlock **502** is at ~10^{-6} torr (the same pressure as process chamber **522**), valve **506** must be closed. Since lower loadlock **505** is at atmosphere for pallet transfer, valve **517** must be closed to preserve vacuum in process chamber **522** and upper loadlock **502**. Two sets of bi-directional motor-driven rollers **623** and **624** define pallet storage slots in upper loadlock **502**, while two more sets of bi-directional motor-driven rollers **625** and **626** define two storage slots in lower loadlock **505**. The exchange of pallet **603** (containing an already-tested FPDS) will be illustrated in FIG. **55**. The FPDS in pallet **601** will be tested after testing of the FPDS in pallet **600** is complete.

FIG. **52** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, pallet elevator **629** is indexing down (arrow **612**) to enable the insertion of unprocessed pallet **604** from pallet elevator **629** into the upper slot (defined by bi-directional motor-driven rollers **625**) of lower loadlock **505**.

FIG. **53** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, unprocessed pallet **604** is being inserted (arrow **613**) from pallet elevator **629** into lower loadlock **505** by bi-directional motor-driven rollers **621** and **625**.

FIG. **54** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, pallet elevator **629** is indexing down (arrow **614**) to enable removal of processed pallet **603** from lower loadlock **505**.

FIG. **55** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, processed pallet **603** is being

removed (arrow **615**) from lower loadlock **505** into pallet elevator **629**. Pallet **603** is supported and moved out of lower loadlock **505** by bi-directional motor-driven rollers **621** and **626**.

FIG. **56** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, pallet elevator **629** is indexing down (arrow **616**) to enable the insertion of unprocessed pallet **605** from pallet elevator **629** into the lower slot (defined by bi-directional motor-driven rollers **626**) of lower loadlock **505**

FIG. **57** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, unprocessed pallet **605** is being inserted (arrow **617**) from pallet elevator **629** into lower loadlock **505** by bi-directional motor-driven rollers **620** and **626**.

FIG. **58** is a schematic view through section H-H in FIG. **41** of the FPDS testing system 120 s after FIG. **51** (see timing diagram in FIG. **64**) showing an FPDS in pallet **604** being tested by optics assembly **520** as pallet **604** moves into process chamber **522** (arrow **648**) from lower loadlock **505** through open valves **517** and **518**. During testing, pallet **604** is supported and moved into/out of process chamber **522** by bi-directional motor-driven rollers **625** and **627**. Simultaneously, processed pallet **600** is being removed (arrow **618**) from upper loadlock **502** through open valve **506** into pallet elevator **629**. Pallet **600** is being supported and moved out of upper loadlock **502** by bi-directional motor-driven rollers **622** and **623**. Since lower loadlock **505** is at ~10^{-6} torr (the same pressure as process chamber **522**), valve **507** must be closed. Since upper loadlock **502** is at atmosphere for pallet transfer, valve **516** must be closed to preserve vacuum in process chamber **522** and lower loadlock **505**.

PALLET DISASSEMBLY AND FPDS REMOVAL FROM PALLET ELEVATOR

FIGS. **59-63** are a sequence of schematic side views of the FPDS testing system in FIG. **42**, showing various aspects of the process of disassembling pallets in pallet elevator **629**, followed by transfer of FPDSs into/out of pallet elevator **629**,

resting on supports **710**. In FIGS. **59-63**, more details of the internal mechanisms in pallet elevator **629** are shown which were omitted for clarity in FIGS. **51-58** – specifically, three pin plates **705-707**, which are mounted as shown and are supported and moved together vertically by an actuator (not shown). Dual loadlock **575** and process chamber **522** rest on supports **714** and **718**, respectively, and are not affected by any of the operations of pallet elevator **629** interacting with the FPD fab environment. The timeline in FIG. **64** shows that the pallet disassembly operations illustrated in FIGS. **59-60** (given in more detail in FIGS. **27-30**) occur in the intervals 50 - 65 s and 170 – 185 s, while the FPDS transfer operations illustrated in FIGS. **61-63** occur in the intervals 65 – 95 s and 185 – 215 s.

FIG. **59** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing two assembled pallets **701** and **702** in pallet elevator **629** (refer to FIG. **27**). Pallets **701** and **702** are supported by two sets of bi-directional motor-driven rollers **620** and **621**, respectively, which define the upper two storage slots in pallet elevator **629**. The third slot in pallet elevator **629**, defined by a third set of bi-directional motor-driven rollers **622**, is empty in this view.

FIG. **60** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing the two pallets **701** and **702** of FIG. **59** now disassembled in pallet elevator **629** (refer to FIG. **30**). Pallet top **720**, FPDS **721**, and pallet bottom **722** are now separated by pin plate **705**, which has been moved vertically upwards. Pallet top **723**, FPDS **724**, and pallet bottom **725** are now separated by pin plate **706**, which has been moved vertically upwards. Pin plate **707** has also moved vertically upwards (even though there is no pallet in the lower slot defined by bi-directional motor-driven rollers **622**) because all three pin plates **705-707** are connected to the same vertical actuator (not shown).

FIG. **61** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing a three-blade robot entering (arrow **740**) pallet elevator **629** (refer to FIG. **31**). The three-blade robot comprises three end effectors (also called "blades") **731-733** and end effector mount **730**. End effector **731** passes between FPDS **721** and pallet bottom **722**; end effector **732** passes between FPDS **724** and pallet bottom **725**; and end effector **733** enters an empty slot without a pallet. Pallet tops **720** and **723** are supported on pin plates **705** and **706**, respectively. Pin plates **705-707** may be designed with trenches which fit around bi-directional motor-driven

rollers **620-622**, respectively, to enable pin plates **705-707** to move far enough up to disassemble pallets without interference from rollers **620-622**.

FIG. **62** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing the three-blade robot lifting (arrow **741**) tested FPDSs **721** and **724** off pin plates **705** and **706**, respectively (refer to FIG. **32**).

FIG. **63** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing the three-blade robot removing (arrow **742**) tested FPDSs **721** and **724** from pallet elevator **629** into the FPD fab (refer to FIG. **33**).

The reverse process from that shown in FIGS. **59-63** is used to insert FPDSs **721** and **724** (which now should be assumed to be ready for testing, not already tested) into pallet elevator **629**:

1) FIG. **63**: the three-blade robot transports (arrow **742** reversed) FPDSs **721** and **724** into pallet elevator **629.**
2) FIG **62**: the three-blade robot lowers (arrow **741** reversed) FPDSs **721** and **724** onto pin plates **705** and **706**, respectively.
3) FIG. **61**: the three-blade robot withdraws (arrow **740** reversed) from pallet elevator **629**.
4) FIG. **60**: pin plates **705** and **706** are now ready to assemble pallets **701** and **702** (see FIG. **59**).
5) Fig. **59**: pin plates **705** and **706** have been lowered by the pin plate actuator (not shown) to assemble pallets **701** and **702**, respectively.

The procedure between FIGS. **63-59** (in reverse) is shown in detail in FIGS. **33-27** (also in reverse).

The pallet disassembly/assembly and FPDS removal/insertion operations shown schematically in FIGS. **59-63** are performed in pallet elevator **629** at atmospheric pressure (preferably in a clean dry nitrogen atmosphere), in parallel with FPDS testing and loadlock venting/pumpdown as shown in the timing diagram in FIG. **64**.

TIMING DIAGRAM FOR THE FIRST EMBODIMENT OF AN FPDS TESTING SYSTEM

FIG. **64** is an operational cycle timing diagram for a first embodiment of an FPDS testing system as described in reference to FIGS. **41** and **42** – the total period

shown is 0 to 240 s, during which time four FPDSs are fully tested by optics assembly **520** in process chamber **522** (see FIG. **43**). In operation, the FPDS test system would then start back at time = 0 s (which is equivalent to 240 s), with another four pallets, going from 0 – 240 s (equivalent to 240 – 480 s) again. The three main subsystems are shown along the left side: pallet elevator **629**, dual loadlock **575** and process chamber **522**. Each horizontal line represents a particular process within the FPDS testing system – the brackets along the left side show which of the three subsystems performs the process (where more than one subsystem performs a process, the brackets overlap):

<u>Substrates Exchange</u> – the process of transporting FPDSs between pallet elevator **629** and the FPD fab using a three-blade robot. Details of the FPDSs exchange process, which occurs from 65 – 95 s and 185 – 215 s, are given in FIGS. **61-63**. While FPDSs are being exchanged, the pallets must be in the disassembled state.

<u>Pallets Disassembly</u> – the process of separating a pallet into a pallet top and a pallet bottom, to enable one FPDS to be removed and another FPDS to be inserted (Substrates Exchange line, above). Details of the pallet disassembly process, which takes place from 50 - 65 s and 170 - 185 s, are given in FIGS. **27-30**. Pallet disassembly occurs within pallet elevator **629**.

<u>Pallets Assembly</u> – the process of assembling a pallet from a pallet top and a pallet bottom with an FPDS is the inverse of pallet disassembly – refer to FIGS. **30-27** (reverse arrows **210**, **212**, **214**, and **216**) and takes place from 95 - 110 s and 215 - 230 s. Pallet assembly occurs within pallet elevator **629**.

<u>Substrates Alignment</u> – after a pallet is assembled, it is necessary to align the pallet top with the FPDS within the pallet, as described schematically in FIGS. **34-39B**. Substrates alignment, which takes place from 110 – 140 s and 230 – 20 s (equivalent to 230 – 260 s), ensures that all the contactors **425** in pallet top **110** align with test pads **426** on FPDS **120** (see FIG. **17**). Substrate alignment occurs within pallet elevator **629**.

<u>Pallets Exchange</u> - after the pallets with untested FPDSs in pallet elevator **629** are assembled and aligned, two other pallets containing tested FPDSs are removed from dual loadlock **575** into pallet elevator **629**. The two pallets with untested FPDSs are then inserted into dual loadlock **575** from pallet elevator **629**, as

described in FIGS. **51-57**. Over the time interval from 20 – 50 s, pallet exchange is to/from lower loadlock **505**, while over 140 – 170 s, pallet exchange is to/from upper loadlock **502**. Pallet exchange can occur between pallet elevator **629** and dual loadlock **575** only when one of the loadlocks **502** or **505** in dual loadlock **575** has been vented to atmospheric pressure and either valve **506** (upper loadlock **505**) or valve **507** (lower loadlock **505**) is open (see FIGS. **51-58**).

<u>Vent Upper Loadlock</u> – upper loadlock **502** is vented to atmospheric pressure from 120 – 140 s to enable pallet exchange between pallet elevator **629** and upper loadlock **502**. Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within upper loadlock **502** to reduce the risk of contaminating or breaking the FPDSs within upper loadlock **502**.

<u>Pump Upper Loadlock</u> - after pallet exchange between upper loadlock **502** and pallet elevator **629** is complete, upper loadlock **502** is pumped down over the period 170 – 235 s. A number of different pumps (not shown) may be used in combination to minimize the pumpdown time as is familiar to those skilled in the art of vacuum system design:

a. <u>Air Ejectors</u> – this type of pump uses pressurized gas to remove large quantities of gas from a chamber near atmospheric pressure. A typical air ejector would be the PIAB model #MLL1200 with 255 L/s pumping speed at 760 torr, dropping to 12.4 L/s at 160 torr. Below 160 torr, the air ejector(s) would be valved off from upper loadlock **502**.

b. <u>Mechanical Pumps</u> – this type of pump uses a piston to physically remove gas from the chamber over a pressure range from atmosphere down to 0.002 torr. A typical mechanical pump would be the Edwards model #iQDP80/iQMB1200 F with 12 L/s pumping speed at 760 torr, rising to 260 L/s at 0.1 torr, then falling back to 66 L/s at 0.002 torr. When upper loadlock **502** is below 0.002 torr, the mechanical pump(s) would be valved off from upper loadlock **502**.

c. <u>Turbomolecular Pumps</u> – this type of pump gives high pumping speeds for chambers at pressures of ~0.2 torr and below. A typical turbomolecular pump would be the Osaka model #TG1810 with 140 L/s pumping speed at ~0.2 torr, rising to 1800 L/s over 10^{-3} -10^{-6} torr.

Above 0.15 torr, the turbopump(s) would be valved off from upper loadlock **502**.

A typical loadlock volume would be ~1000 L, with four air ejectors, two mechanical pumps and a turbopump needed to achieve pumpdown times of ~65 s from atmosphere to ~10^{-6} torr.

Note that the lower loadlock **505** pumpdown occurs from 50 - 115 s (see below), so there is no overlap in time between the lower loadlock **505** pumpdown and the upper loadlock **502** pumpdown – this means that the same set of pumps can be used for pumping down both the upper **502** and lower **505** loadlocks. If it is possible to maintain ~10^{-6} torr in upper loadlock **502** and lower loadlock **505** using only the process chamber **522** pumping system (not shown), then no dedicated pumps for either the upper **502** or lower **505** loadlocks will be necessary. Otherwise, two small sustaining turbopumps (one for each of the upper **502** and lower **505** loadlocks) could be used to maintain ~10^{-6} torr after the main set of pumpdown pumps (described above) is diverted over to the other loadlock.

<u>Upper Loadlock at Air or Vacuum</u> – after pumping upper loadlock **502** down to ~10^{-6} torr, one or more turbopumps (not shown) may remain connected to upper loadlock **502**, maintaining upper loadlock **502** at ~10^{-6} torr (the same vacuum level as in process chamber **522**) over the period 235 – 120 s. Note that 120 s is equivalent to 360 s (= 120 s + 240 s cycle time), since the FPD testing system cycles through the full timeline in FIG. **64** repeatedly, testing four FPDSs every 240 s. It may be possible to maintain ~10^{-6} torr in upper loadlock **502** using only the process chamber **522** pumping system (not shown).

<u>Vent Lower Loadlock</u> – lower loadlock **505** is vented to atmospheric pressure from 0 – 20 s to enable pallet exchange between pallet elevator **629** and lower loadlock **505**. Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within lower loadlock **505** to minimize the risk of contaminating or breaking the FPDSs within lower loadlock **505**.

<u>Pump Lower Loadlock</u> - after pallet exchange between lower loadlock **505** and pallet elevator **629** is complete, lower loadlock **505** is pumped down over the period 50 – 115 s. The same pumping considerations apply to lower loadlock **505** as apply to upper loadlock **502**.

Lower Loadlock at Air or Vacuum – after pumping lower loadlock **505** down to $\sim10^{-6}$ torr, one or more turbopumps (not shown) may remain connected to lower loadlock **505**, maintaining lower loadlock **505** at $\sim10^{-6}$ torr (the same vacuum level as in process chamber **522**) over the period 115 – 240 s. It may be possible to maintain $\sim10^{-6}$ torr in lower loadlock **505** using only the process chamber **522** pumping system (not shown).

Index Dual Loadlock – the dual loadlock **575** has four slots for supporting pallets. These slots are defined by the four sets of bi-directional motor-driven rollers **623-626**. (see FIG. **43**). For insertion/removal of pallets into/from process chamber **522**, is necessary to move dual loadlock **575** vertically to align each of the four slots with rollers **527** in process chamber **522** – this vertical motion and alignment is called "indexing". Precise indexing (to precisions <1 mm) is preferable for the pallet to align properly with optics assembly **520** since during almost the full period of e-beam testing, a pallet is supported both by rollers in dual loadlock **575** (i.e., one of the four sets of rollers **623-626**) as well as by rollers **627** in process chamber **522** (see FIG. **43** – note that pallet **500** is being tested by optics assembly **520** while still being partially supported by bi-directional motor-driven rollers **623** in upper loadlock **502**). During indexing, which occurs four times during the 240 s cycle (55 – 60 s, 115 – 120 s, 175 – 180 s, and 235 – 240 s), dual loadlock **575** moves with respect to process chamber **522**, necessitating a movable vacuum seal between dual loadlock **575** and process chamber **522**, as discussed in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein.

Insert or Remove Pallet – this line in the timing diagram covers both the insertion of pallets from dual loadlock **575** into process chamber **522** (times 0 – 5 s, 60 – 65 s, 120 – 125 s, and 180 – 185 s – marked "I"), as well as the removal of pallets from process chamber **522** into dual loadlock **575** (times 45 – 55 s, 105 – 115 s, 165 – 175 s, and 225 – 235 s – marked "R"). The removal times are longer than the insertion times because alignment and testing of an FPDS begins after the pallet has traveled only a short distance into process chamber **522** (see FIG. **43**), while pallet removal involves travelling back (reverse arrow **530** in FIG. **43**) the full length of process chamber **522**.

Align and Test Substrate – this line represents the times required for alignment and testing of FPDSs (in pallets) using optics assembly **520** in process

chamber **522**. "Alignment" refers to the process of locating alignment marks (not shown – these are different marks from alignment marks **1001** in FIGS. **34-38)** using each of the multiple e-beams from optics assembly **520**. When the alignment marks have been located with the e-beams from optics assembly **520**, it is then possible to locate the various pixel electrodes (not shown) on FPDS **120** to perform e-beam testing of individual pixels for defects as discussed in U. S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 and in U. S. Patent Application Ser. No. 11/093,000 filed March 28, 2005, both incorporated by reference herein. The "align and test substrates" operation occurs four times during the 240 s cycle: 5 – 45 s, 65 – 105 s, 125 – 165 s, and 185 – 225 s.

SECOND EMBODIMENT OF AN FPDS TESTING SYSTEM

The first embodiment of the present invention discussed above requires a separate pallet elevator **629** to feed pallets into dual loadlock **575**. After loading into pallet elevator **629**, pallets are transported to either the upper **502** or lower **505** loadlocks in dual loadlock **575**, pumped down, and then inserted into process chamber **522** for e-beam testing. One disadvantage of this arrangement is the need for FPD fab floor space to accommodate pallet elevator **629**. Another disadvantage is the extra cost required for a separate pallet elevator **629**, in addition to the dual loadlock **575** and process chamber **522**.

A second embodiment of the present invention will now be described in reference to FIGS. **65–70** that eliminates these disadvantages by integrating the pallet assembly/disassembly functions of the pallet elevator into the dual loadlock. A summary of this embodiment includes:

1) Dual loadlock **899**, which serves as the interface between the FPD fab and the FPDS testing system. The functions of dual loadlock **899** are the following:
   a. Enables a robot to transport FPDSs from the FPD fab into the FPDS testing system.
   b. Assembles pallets containing the FPDSs for testing.
   c. Performs alignment between the contactors in the pallets and the test pads on the FPDSs.

d. Pumps down to a vacuum level equal to that in process chamber **804**.

e. Assists in the transport of the pallets (one at a time) into process chamber **804** for e-beam testing.

f. Assists in the removal of the pallet (one at a time) from process chamber **804** after e-beam testing.

g. Vents to atmospheric pressure.

h. Disassembles the pallets with the tested FPDSs.

i. Enables the robot to transport the tested FPDSs out of the FPDS testing system to the FPD fab.

2) A process chamber **804** which has the following functions:

a. Assists in the transport of one pallet at a time from the dual loadlock.

b. Tests for defective pixels on the FPDS in the pallet using one or more electron beams.

c. Assists in the transport of one pallet at a time back into the dual loadlock after testing.

One disadvantage of the second embodiment relative to the first embodiment is the increased complexity of mechanisms within dual loadlock **899**. Another disadvantage is the need for higher pumping capacity to enable pumpdown times consistent with the timeline in FIG. **70** due to the larger volume of dual loadlock **899** compared with dual loadlock **575**.

FIG. **65** is a schematic top view of a second embodiment of an FPDS testing system embodying the present invention, including dual loadlock **899** and process chamber **804**. Dual loadlock **899** comprises two loadlocks **800** and **801** (see FIGS. **67-69**) which cycle between atmospheric pressure and the vacuum level in the process chamber **804**, typically ~10^{-6} torr. Interface plate **805** is part of the sliding vacuum seal between dual loadlock **899** and process chamber **804**. Aspects of moving vacuum seals are discussed in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein. Process chamber **804** remains at ~10^{-6} torr except during maintenance. Cross-section K-K is also illustrated in FIG. **65**.

FIG. **66** is a schematic side view of the FPDS testing system in FIG. **65**. Valves **802** and **803** enable insertion/removal of pallets into/from dual loadlock **899**. Dual loadlock **899** sits on supports **810** which provide vertical motion capability for dual loadlock **899** to enable the two-way transfer of pallets: 1) out of process chamber **804** going into any slot in dual loadlock **899**, and 2) out of any slot in dual loadlock **899** going into process chamber **804** (see FIG. **67** for the definitions of loadlock slots). Process chamber **804** sits on fixed supports **814**. All of supports **810** and **814** should provide vibration isolation to dual loadlock **899** and process chamber **804**, respectively, to ensure that there is no vibration of pallets **807** and **907** relative to optics assembly **806** (see FIGS. **67** and **69**). A two-blade robot comprising end effectors **831-832** and end effector mount **830** can be seen entering dual loadlock **899** from the left. Interface plate **805** extends high enough to accommodate the range of motion of dual loadlock **899** relative to process chamber **804** required for indexing all four slots in dual loadlock **899** with process chamber **804** (compare FIG. **67** with FIG. **69**).

FIG. **67** is a schematic view through section K-K of the FPDS testing system in FIG. **65**. Dual loadlock **899** includes upper loadlock **800** and lower loadlock **801**. In FIG. **67**, a closed valve (such as valves **802** and **861**) is indicated by an "X", while an open valve (such as valves **803**, **860**, and **862**) has no "X". Two sets of bi-directional motor-driven rollers **820** and **821** define two pallet storage slots in upper loadlock **800**, and another two sets of bi-directional motor-driven rollers **852** and **855** define two pallet storage slots in lower loadlock **801**. Rollers **820**, **821**, **852**, and **855** have two functions:

1) Supporting pallets within dual loadlock **899** – each set of rollers **820**, **821**, **852**, and **855** defines a separate pallet storage slot within dual loadlock **899**.

2) Assisting in transferring pallets between dual loadlock **899** and process chamber **804** (working in conjunction with bi-directional motor-driven rollers **856** in process chamber **804**).

Bi-directional motor-driven rollers **856** support and transport pallets within process chamber **804**. Pallet **807** is shown being transported (arrow **823**) under optics assembly **806** by two sets of bi-directional motor-driven rollers: rollers **820** in upper loadlock **800**, and rollers **856** in process chamber **804**. Upper loadlock

chamber **800** has two valves: valve **802** allowing insertion/removal of pallets into/from dual loadlock **899** from/to the FPD fab, and valve **860** allowing insertion/removal of pallets into/from process chamber **804**. For pallet transfer to/from process chamber **804**, upper loadlock **800** must be at the same pressure as process chamber **804** (~10^{-6} torr) – this requires valve **802** to be closed, and valves **860** and **862** to be open. Valve **862** (which normally remains open) enables process chamber **804** to be sealed off from dual loadlock **899** for maintenance on either dual loadlock **899** or process chamber **804**. Lower loadlock **801** is shown with valve **803** open to enable the removal/insertion of FPDSs. Since FPDS removal requires lower loadlock **801** to be at atmospheric pressure, valve **861** must be closed to preserve the ~10^{-6} torr pressure in upper loadlock **800** and process chamber **804**. Optics assembly **806** comprises the linear array of electron columns **1211** and the linear array of corresponding detectors **1240** (see FIG. **2**). An electron beam testing procedure for FPDSs is discussed in detail in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein.

During the time required to test the FPDSs in pallets **807** and **808** (see timeline in FIG. **70**), two pallets with already-tested FPDSs are disassembled (see FIGS. **27-30**) within lower loadlock **801** so that the already-tested FPDSs (not shown) can be removed by a two-blade robot through valve **803**. Two FPDSs **840** and **841** ready for testing are then inserted into lower loadlock **801** by the two-blade robot consisting of end effectors (or "blades") **831** and **832** and end effector mount **830** – the two-blade robot is shown leaving (arrow **824**) lower loadlock **801** after loading the two FPDSs **840** and **841** onto pin plates **857** and **858**, respectively (see FIGS. **33-31** with arrows **250**, **246**, and **244** reversed). Valve **803** would then be closed and lower loadlock **801** pumped down to the same pressure as in process chamber **804** (typically ~10^{-6} torr). While lower loadlock **801** is pumping down, the two pallets in lower loadlock **801** are reassembled by pin plates **857** and **858** (see FIGS. **30-27** with arrows **214**, **212**, and **210** reversed). The next step is alignment of pallet tops **850** and **853** to FPDSs **840** and **841**, respectively, (see timeline in FIG. **70**). After assembly, the pallet in the upper slot (defined by rollers **852**) in lower loadlock **801** will consist of pallet top **850** and pallet bottom **851** with FPDS **840** contained therein; the pallet in the lower slot (defined by rollers **855**) in

lower loadlock **801** will consist of pallet top **853** and pallet bottom **854** with FPDS **841** contained therein.

A vertical actuator (not shown) moves pin plates **822** and **823** vertically to enable the pallet disassembly [assembly] procedure illustrated in FIGS. **27-30 [30-27]** to be performed simultaneously on both pallets within upper loadlock **800**. In FIG. **67**, pin plates **822** and **823** are shown in the lower position, leaving pallets **807** and **808** assembled (see FIG. **27**) and allowing pallets **807** and **808** to be transported by rollers **820** and **821**, respectively. Pin plates **857** and **858** are in their upper position, disassembling the two pallets in lower loadlock **801** (see FIG. **30**).

FIG. **68** is a schematic view through section L-L of the FPDS testing system in FIG. **66** at the same point on the timeline (FIG. **70**) as in FIG. **67**. Because pallet **807** has moved (arrow **823**) mostly into process chamber **804**, pin plate **822** in upper loadlock **800** can be clearly seen. In particular, the trenches **865** in pin plate **822** which allow clearance for bi-directional motor-driven rollers **820** are visible, along with both long pins **204** and short pins **206**. The two-blade robot (comprised of end effectors **831**, **832**, and end effector mount **830**), is leaving (arrow **824**) lower loadlock **801** at the left.

FIG. **69** is a schematic view through section K-K of the FPDS testing system in FIG. **65** showing an FPDS in pallet **907** from lower loadlock **801** being tested while the two-blade robot is entering upper loadlock **800**. The view in FIG. **69** is 120 s after FIG. **67** – all the functions occurring in upper loadlock **800** in FIG. **67** are now occurring in lower loadlock **801**, and all the functions occurring in lower loadlock **801** in FIG. **67** are now occurring in upper loadlock **800**. 120 s after FIG. **69**, the FPD testing system would again be in the status shown in FIG. **67** (see the timeline in FIG. **70**).

After testing of the FPDSs in pallets **807** and **808** as described in reference to FIG. **67**, valve **860** was closed and dual loadlock **899** indexed up to enable pallet **907** from lower loadlock **801** to be inserted into process chamber **804** through open valves **861** and **862**. The same testing procedure described in FIG. **67** for pallets **807** and **808** is then followed for pallets **907** and **908** from lower loadlock **801**. During e-beam testing, pallet **907** in the upper slot of lower loadlock **802** is supported and transported (arrow **890**) by bi-directional motor-driven rollers **852** and **856**, and pallet **908** in the lower slot of lower loadlock **801** is supported and transported by bi-

directional motor-driven rollers **855** and **856**. During the time required to test the FPDSs in pallets **907** and **908** from lower loadlock **801**, upper loadlock **800** is vented to atmosphere, pallets **807** and **808** (see FIG. **67**) are disassembled, and the two already-tested FPDSs removed by the two-blade robot. Pallet item numbers **807** and **808** are indicated in brackets and the operation of removal indicated by arrow **891**. Next, two FPDSs **940** and **941** ready for testing are inserted, followed by pallet reassembly and alignment of pallet tops **950** and **953** to FPDSs **940** and **941**, respectively. Insertion of FPDSs **940** and **941** would be indicated by a reverse direction of arrow **891**. After assembly, the pallet in the upper slot (defined by rollers **820**) of upper loadlock **800** will consist of pallet top **950** and pallet bottom **951** with FPDS **940** therein; the pallet in the lower slot (defined by rollers **821**) of upper loadlock **800** will consist of pallet top **953** and pallet bottom **954** with FPDS **941** therein. The two-blade robot (comprised of end effectors **831**, **832**, and end effector mount **830**), is leaving (arrow **891**) upper loadlock **800** at the left through open valve **802**.

For pallet transfer to/from process chamber **804**, lower loadlock **801** must be at the same pressure as process chamber **804** (~10^{-6} torr) – this requires valve **803** to be closed, and valves **861** and **862** to be open to allow pallet transfer. Upper loadlock **800** is shown with valve **802** open to enable the removal/insertion of FPDSs. . Since FPDS removal requires upper loadlock **800** to be at atmospheric pressure, valve **860** must be closed to preserve the ~10^{-6} torr pressure in lower loadlock **801** and process chamber **804**.

This procedure of toggling between testing FPDSs from the upper **800** and lower **801** loadlocks enables high system throughput since there is always one loadlock (either upper loadlock **800** or lower loadlock **801**), pumped down and ready to insert pallets into process chamber **804** for testing by optics assembly **806**. All other operations, such as loadlock pumpdown and venting, pallet assembly/disassembly, pallet top-to-FPDS alignment, and FPDS insertion/removal are performed in parallel with e-beam testing and thus have no effect on system throughput.

Process chamber **804** in the second embodiment of the present invention functions identically to process chamber **522** in the first embodiment, including all aspects of e-beam testing, X-Y-Yaw position measurement (FIGS. **2** and **45-50**), and

communications to/from the pallet (FIGS. **2** and **10-12**). The pallet design (FIGS. **13-16**) and pallet disassembly and assembly procedures (FIGS. **27-30** and **30-27**, respectively) are also identical for the two embodiments.

TIMING DIAGRAM FOR THE SECOND EMBODIMENT OF AN FPDS TESTING SYSTEM

FIG. **70** is an operational cycle timing diagram for the second embodiment of an FPDS testing system in FIGS. **65** and **66** – the total period shown is 0 to 240 s, during which time four FPDSs are fully tested by optics assembly **806** in process chamber **804** (see FIG. **67**). In operation, the FPD testing system would then start back at time = 0 s (which is equivalent to 240 s), with another four pallets, going from 0 – 240 s (equivalent to 240 – 480 s) again. The differences and similarities of the second embodiment shown in FIGS. **65** and **66** (with a timing diagram in FIG. **70**) relative to the first embodiment in FIGS. **41** and **42** (with a timing diagram in FIG. **64**) are:

1) No pallet elevator – the functions of pallet elevator **629** in the first embodiment are now performed within dual loadlock **899** in the second embodiment.

2) Dual loadlock **899** contains pin plates **822-823** (in upper loadlock **800**) and pin plates **857-858** (in lower loadlock **801**). In the second embodiment, instead of transferring pallets out to a pallet elevator, FPDSs are directly inserted and removed from dual loadlock **899**. The pin plate actuators for the second embodiment must operate within a vacuum environment in dual loadlock **899**, unlike the atmospheric pressure environment in pallet elevator **629** – this may add some complexity to the system as well as the need for in-vacuum mechanical motions (i.e., pins **204** and **206** must slide through holes **164** and **166**, respectively, under vacuum).

3) The upper **800** and lower **801** loadlocks are now larger to accommodate pin plates **822-823** and **857-858**, respectively – this will require increased pumping capacity to achieve the necessary loadlock pumpdown times to maintain the desired system throughput (compare timelines in FIGS. **64** and **70**). This also requires valves **802-803** and

860-861 in the second embodiment to be larger (wider in the vertical direction) than the corresponding valves **506-507** and **516-517**, respectively, in the first embodiment (compare FIGS. **43** and **67**).

4) Reduced system footprint – the FPDS testing system footprint is substantially reduced in the second embodiment by eliminating pallet elevator **629** – this is a significant advantage since FPD fab floor space is typically at a premium.

5) Process chamber **804** – essentially unchanged from process chamber **522** in the first embodiment – the only significant exception being supports **814**, which must be taller than supports **718** to accommodate the increased travel of dual loadlock **899** during indexing relative to the travel of dual loadlock **575** (compare FIGS. **42** and **66**).

The two main subsystems are shown along the left side of FIG. **70**: dual loadlock **899** and process chamber **804**. Each horizontal line represents a particular process within the FPDS testing system – the brackets along the left side show which of the two subsystems performs the process (where more than one subsystem performs a process, the brackets overlap):

Substrates Exchange – the process of transporting FPDSs between dual loadlock **899** and the FPD fab using a two-blade robot. The substrate exchange process occurs from 20 – 50 s (into/out of lower loadlock **801** – see FIGS. **67-68**) and 140 – 170 s (into/out of upper loadlock **800** – see FIG. **69**) in the 240 s cycle. While FPDSs are being exchanged, the pallets must be in the disassembled state and the respective loadlock must be at atmospheric pressure.

Pallets Disassembly – the process of separating a pallet into a pallet top and a pallet bottom for holding a FPDS, to enable the FPDS to be removed and another FPDS to be inserted (Substrates Exchange line, above). Details of the pallet disassembly process, which takes place from 5 - 20 s (in lower loadlock **801**) and 125 - 140 s (in upper loadlock **800**), are given in FIGS. **27-30**. Simultaneously with pallet disassembly, the loadlock chamber containing the pallets being disassembled continues venting: either lower loadlock **800** (during 0 - 20 s) or upper loadlock **801** (during 120 - 140 s).

Pallets Assembly – the process of assembling a pallet from a pallet top and a pallet bottom with a FPDS is the inverse of pallet disassembly – refer to FIGS. **30-27**

(reverse arrows **210**, **212**, **214**, and **216**). Pallet assembly takes place from 50 – 65 s (in lower loadlock **801**) and 170 – 185 s (in upper loadlock **800**). Simultaneously with pallet assembly, the loadlock chamber containing the pallets under assembly starts pumping down: either lower loadlock **800** (during 50 – 115 s) or upper loadlock **801** (during 170 – 235 s).

Substrates Alignment – after a pallet is assembled, it is necessary to align the pallet top with the FPDS within the pallet, as described schematically in FIGS. **34-39B**. Substrates alignment, which takes place from 65 – 100 s (in lower loadlock **801**) and 185 – 220 s (in upper loadlock **800**), ensures that all the contactors **425** in pallet top **110** align with the test pads **426** on FPDS **120** (see FIG. **17**). Simultaneously with substrates alignment, the loadlock chamber containing the pallets being aligned continues pumping down: either lower loadlock **800** (during 50 – 115 s) or upper loadlock **801** (during 170 – 235 s).

Vent Upper Loadlock – upper loadlock **800** is vented to atmospheric pressure from 120 – 140 s to enable FPDS exchange between upper loadlock **800** and the FPD fab (outside the system – not shown). Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within upper loadlock **800** to reduce the risk of contaminating or breaking the FPDSs within upper loadlock **800**.

Pump Upper Loadlock - after FPDS exchange between upper loadlock **800** and the FPD fab is complete, upper loadlock **800** is pumped down over the period 170 – 235 s. The same combination of different pumps (not shown - see FIG. **64**) as were described in the first embodiment may be used to minimize the pumpdown time as is familiar to those skilled in the art of vacuum system design. A typical loadlock volume would be ~2000 L, with multiple air ejectors, mechanical pumps and turbopumps needed to achieve pumpdown times of ~65 s from atmosphere to ~10^{-6} torr – due to the larger volume of upper loadlock **800** relative to upper loadlock **502**, a larger number of pumps may be required to achieve the necessary ~65 s pumpdown time.

Note that the lower loadlock **801** pumpdown occurs from 50 - 115 s (see below), so there is no overlap in time between the lower loadlock **801** pumpdown and the upper loadlock **800** pumpdown – this means that the same set of pumps can be used for pumping down both the upper and lower loadlocks. With apparatus

sufficient to maintain ~10^{-6} torr in upper loadlock **800** and lower loadlock **801** using only the process chamber **804** pumping system (not shown), then no dedicated pumps for either the upper **800** or lower **801** loadlocks will be necessary. Otherwise, two small sustaining turbopumps (one for each of the upper **800** and lower **801** loadlocks) could be used to sustain ~10^{-6} torr after the main set of pumpdown pumps (described above) is diverted over to the other loadlock.

Upper Loadlock at Air or Vacuum – after pumping upper loadlock **800** down to ~10^{-6} torr, one or more turbopumps (not shown) may remain connected to upper loadlock **800**, maintaining upper loadlock **800** at ~10^{-6} torr (the same vacuum level as in process chamber **804**) over the period 235 – 120 s. Note that 120 s is equivalent to 360 s (= 120 s + 240 s cycle time), since the FPD testing system cycles through the full 240 s timeline in FIG. **70** repeatedly, testing four FPDSs every 240 s. Alternatively, ~10^{-6} torr in upper loadlock **800** can be maintained with a compatible process chamber **804** pumping system (not shown).

Vent Lower Loadlock – lower loadlock **801** is vented to atmospheric pressure from 0 – 20 s to enable FPDS exchange between lower loadlock **801** and the FPD fab (outside the tool – not shown). Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within lower loadlock **801** to reduce the risk of contaminating or breaking the FPDSs within lower loadlock **801**.

Pump Lower Loadlock - after FPDS exchange between lower loadlock **801** and the FPD fab is complete, lower loadlock **801** is pumped down over the period 50 – 115 s. The same pumping considerations apply to lower loadlock **801** as applied to upper loadlock **800**.

Lower Loadlock at Air or Vacuum – after pumping lower loadlock **801** down to ~10^{-6} torr, one or more turbopumps (not shown) may remain connected to lower loadlock **801**, maintaining lower loadlock **801** at ~10^{-6} torr (the same vacuum level as in process chamber **804**) over the period 115 – 240 s. Alternatively, ~10^{-6} torr in lower loadlock **801** can be maintained with a compatible process chamber **804** pumping system (not shown).

Index Dual Loadlock – the dual loadlock **899** has four slots for supporting pallets. These slots are defined by the four sets of bi-directional motor-driven rollers **820**, **821**, **852**, and **855**. (see FIG. **67**). For insertion/removal of pallets into/from

process chamber **804**, it is necessary to move dual loadlock **899** vertically to align each of the four slots with rollers **856** in process chamber **804** – this vertical motion and alignment is called "indexing". Precise indexing (to precisions <1 mm) is preferable for the pallet to align properly with optics assembly **806** since during almost the full period of e-beam testing, a pallet is supported by both the rollers in dual loadlock **899** (i.e., one of the four sets of rollers **820**, **821**, **852**, or **855**) and rollers **856** in process chamber **804** (see FIG. **67** – note that pallet **807** is being tested by optics assembly **806** while still being partially supported by bi-directional motor-driven rollers **820** in upper loadlock **800**). During indexing, which occurs four times during the 240 s cycle (55 – 60 s, 115 – 120 s, 175 – 180 s, and 235 – 240 s), dual loadlock **899** moves with respect to process chamber **804**, necessitating a movable vacuum seal between dual loadlock **899** and process chamber **804**, as discussed in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein. Sealing plate **805** works in conjunction with the opposing surface on dual loadlock **899** as part of the sliding seal, which optionally may have a bellows seal.

<u>Insert or Remove Pallet</u> – this line in the timing diagram covers both the insertion of pallets from dual loadlock **899** into process chamber **804** (times 0 – 5 s, 60 – 65 s, 120 – 125 s, and 180 – 185 s – marked "I"), as well as the removal of pallets from process chamber **804** into dual loadlock **899** (times 45 – 55 s, 105 – 115 s, 165 – 175 s, and 225 – 235 s – marked "R"). The removal times are longer than the insertion times because alignment and testing of an FPDS begins after the pallet has traveled only a short distance into process chamber **804** (see FIG. **67**), while pallet removal involves travelling back (reverse arrow **823** in FIG. **67**) the full length of process chamber **804**.

<u>Align and Test Substrate</u> – this line represents the times required for alignment and testing of FPDSs (in pallets) using optics assembly **806** in process chamber **804**. "Alignment" refers to the process of locating alignment marks (not shown – these are different marks from alignment marks **1001** in FIGS. **34-38**) using each of the multiple e-beams from optics assembly **806**. When the alignment marks have been located with the e-beams from optics assembly **806**, it is then possible to locate the various pixel electrodes (not shown) on FPDS **120** to perform e-beam testing of individual pixels for defects as discussed in U. S. Patent Application Ser.

No. 11/225,376 filed September 12, 2005 and in U. S. patent Application Ser. No. 11/093,000 filed March 28, 2005, both incorporated by reference herein. The align and test substrates operation occurs four times during the 240 s cycle: 5 – 45 s, 65 – 105 s, 125 – 165 s, and 185 – 225 s.

SCHEMATIC VIEW OF THE ELECTRON OPTICAL COLUMN AND DETECTOR OPTICS

FIG. **71** is a schematic cross-section of an electron optical column **1211** and the corresponding detector **1240** shown in FIG. **2** in a plane containing the optical axis of one column and parallel to the main scan axis. Electrons **1503** are emitted by source tip **1501** under the influence of a high electric field generated by a voltage difference between source tip **1501** and extraction electrode **1504**, typically 2700-3400 V. Suppressor electrode **1502** is typically biased negative relative to source tip **1501** to suppress electron emission from the shank (upper cylindrical portion) of source tip **1501**, since this emission cannot be used to form the electron beam. The source lens includes extraction electrode **1504**, source lens electrode **1505**, and beam-limiting aperture (BLA) **1520**. Electrons passing through BLA **1520** enter the double-deflection beam blanker comprised of electrodes **1507** and **1508**. In FIG. **71**, the blanker is inactivated, so beam **1506** is not deflected off the optical axis, and passes through the blanking and pumping aperture (BPA) **1510** and into the main lens. The purpose of the double-deflection blanker is to turn the beam on and off at the surface of FPDS **120**.

The main lens includes electrodes **1511**, **1512**, and **1513**, forming a focused spot **1521** on the surface of FPDS **120**. The stigmator/deflector **1515** deflects the beam **1230** and corrects beam shape distortions caused by the beam deflection. Detector **1240** collects signal electrons **1244** emitted from the upper surface of the FPDS **120** at location **1521** due to the interaction of the primary beam **1230** with the material in the substrate **120**. A 4000 V bias relative to the substrate surface **120** may be applied to detector **1240**, causing signal electrons **1244** to be attracted to detector **1240**. The detector optics designs in U.S. Patent No. 6,777,675 B2 and U.S. Appl. No. 10/833,949, incorporated by reference herein, illustrate a similar detector optics design (this design is for a generally cylindrically symmetric detector optics). Electrical connections **1212** to column **1211** include cables **1540-1550**,

connecting to optical elements **1501**, **1502**, **1504**, **1505**, **1507**, **1508**, **1510**, **1511**, **1512**, **1513**, and **1515**, respectively.

The X-Y-Yaw data received by system control **1203** from X-Y-Yaw readout **1202** is relayed to optics control **1201** through control link **1220** (see FIG. **2**). Optics control **1201** uses the X-Y-Yaw data to control the deflection signals sent to each of the stigmator/deflectors **1515** through cables **1212** connecting to columns **1211**. By inducing X-Y deflections to beams **1230**, the optics control **1201** can place each beam **1230** in the proper location on the surface of FPDS **120**, counteracting any X, Y, or Yaw errors due to imperfections in the motion of pallet **100** within the process chamber (not shown).

It will be understood by those skilled in the art that the foregoing descriptions are for illustrative purposes only. A number of modifications are possible within the scope of the present invention, such as:

1) The pallet elevator in the first embodiment may serve only as a storage location for assembled pallets, prior to insertion into the dual loadlock, with the pallet disassembly/assembly operations conducted outside the FPDS testing system. The robot would then transfer assembled pallets into/out of the pallet elevator, instead of FPDSs. In this example, there would be no need for pin plates within the pallet elevator, thereby simplifying the system.

2) The dual loadlock in the second embodiment may serve only as a storage location for assembled pallets, prior to insertion into the process chamber, with the pallet disassembly/assembly operations conducted outside the FPDS testing system. The robot would then transfer assembled pallets into/out of the dual loadlock, instead of FPDSs. In this example, there would be no need for pin plates within the dual loadlock, thereby simplifying the system.

3) Instead of applying the present invention to the testing of FPDSs, other large substrate applications are also possible using the present invention:

    a. A system for electron beam direct-write (EBDW) lithography using the present invention is possible. In this example, a simplified pallet design could be used, not requiring internal

drive electronics. The use of a pallet, in conjunction with a linear array of electron beam columns spanning the full width of the substrate, would eliminate the need for costly and complex X-Y stages for moving the FPDS under the electron beam for patterning the thin film transistors and pixel areas.

b. Other processes used for the fabrication of FPDSs are also possible, such as CVD, PVD, etc. In these cases, the pallet would also be simpler than for e-beam testing of FPDSs, since no electrical contacts to the test pads are necessary. Advantages could include control of the FPDS temperature distribution through the use of heaters within the pallet. Instead of an array of electron beam columns, a linear processing head would be substituted – the processing head could be a linear PVD source, or a linear array of CVD gas jets.

4) The present invention can be applied to electron beam FPD testing and/or direct-write lithography systems with arrangements of the electron columns differing from the linear arrangement shown in FIG. **2**. These alternative arrangements include multiple linear arrays of columns, columns in arrangements other than an X-Y grid, or multiple arrays of columns wherein some columns are specifically designed for e-beam direct-writing of small features (such as TFT source, gate and drain lines) while other columns are specifically designed for writing of larger features such as pixel electrodes.

5) The present invention may also be applied to ion beams, instead of electron beams, for various processes to be applied to large substrates, such as:

a. Microanalysis of large substrates for process feedback during fabrication.

b. Ion beam milling or micromachining of large substrates.

c. Ion beam direct-write (IBDW) lithography of large substrates, including, but not limited to FPDSs.

Although the present invention has been described above in terms of specific embodiments, it is anticipated that alterations and modifications thereof will no doubt

become apparent to those skilled in the art. It is therefore intended that the following claims be interpreted as covering all such alterations and modifications as fall within the true spirit and scope of the invention.